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SNOW AND EROSION IN THE PHOSPHATE MINING AREA OF IDAHO

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Final Report to
USDA Forest Service
Intermountain Forest and Range Experiment Station

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College of Agriculture
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SNOWMELT AND EROSION IN THE PHOSPHATE MINING AREA OF IDAHO

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Completion Report to USDA Forest Service
Intermountain Forest and Range Experiment Station
Ogden, Utah

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CONVERSION FACTORS

To Convert From	To	Multiply By
Hectare (ha)	Acre	2.471
Meter (m)	Foot	3.281
Megagram (Mg)	Ton	1.102
Megagram/hectare (Mg/ha)	Ton/acre	0.446
Millimeter (mm)	Inch	0.0394

SUMMARY

A study of snow hydrology and erosion on phosphate mine waste dumps in southeastern Idaho was conducted from May 1976 to July 1979. Annual measurements of rill erosion were made on four dumps. Periodic measurements of snow accumulation were made on the same dumps. In addition, snowdrift profiles were measured on 14 transects located on two sites on natural ground and the four dump sites. A meteorological station was installed on one of the study dumps to provide a continuous record of weather data.

No strong correlations were formed between erosion and the slope, slope length, or age of the dump and snow water equivalent on the dump. In general, there was a weak relationship between erosion and slope length. The pattern of rill formation however, did seem to influence the amount of erosion. The dendritic rill pattern resulted in less erosion per unit area than did the parallel rill pattern, although only one dump displayed both patterns.

Slope steepness was fairly uniform for the study dumps, about 40 percent. With only a small variation in steepness, the variability in erosion among the dumps could not be explained by the slope variability.

Similarly, the variation in measured snow water equivalent on the dump face or the age of the dump did not explain the year to year variation in erosion. The highest amount of erosion was measured following the 1977 winter, when winter precipitation was well below average. The 1978 and 1979 winters had above average and average snowfalls respectively, but resulted in very little erosion, even on new dumps. Observation of the snowmelt pattern and the resulting erosion in these three years does, however, suggest that the amount of erosion is influenced by the pattern of exposure of bare ground. When the melting of the snowpack resulted in exposure of bare ground expanding from the bottom to the top of the dump, more erosion occurred than when the reverse pattern was observed.

Measured snowdrift profiles were compared to the predicted equilbrium profiles of Tabler's topographic snowdrift model. It was found that the study sites could be placed into three groups based on the ground slope of the leeward side of the obstruction. Two of the groups, one with large negative

leeward ground slopes and the other with slightly negative or flat leeward ground slopes, had measured snowdrift slopes greater than the predicted equilbrium snow slope. The third group, with positive leeward ground slopes, had good agreement between the predicted and measured snow slopes.

An intensive snow survey program on one dump showed that drifted snow contributed significantly to the total snow accumulation on the dump face. Strong correlations were found between the water equivalent at a point on the dump and the aspect of the point, as well as the difference in elevation between the dump and a local major drift obstruction.

Daytime sublimation rates during the melt period approached 1 mm/day with nighttime rates of half of this. During the accumulation period, condensation was observed at night. During the melt period, the sublimation could be calculated but lack of snow surface temperature data precluded calculations during periods of below freezing temperatures.

INTRODUCTION

The phosphate mining region of Idaho is composed of some of the richest phosphate reserves in the world. The expansion of mining operations in the future is inevitable and the only question is one of wise development. The purpose of this project is to provide information about snow distribution and erosion on several waste dumps.

The entire area (Figure 1) is one of north and northwest trending ridges which, when combined with the prevailing winter wind and storm patterns, results in considerable accumulation of snow on the leeward side of the slopes. When waste dumps are constructed so that this snow accumulates on the dump, there exists a potential for large amounts of erosion. Observations of erosion due to snowmelt have been made in a previous study in this area. During a study of slope stability on the phosphate mine spoil dumps in 1973, Jeppson and others (1974) observed that north facing slopes had large soil loss due to snowmelt whereas the west facing slopes had very little. The reasons given for this difference were: (1) microscale surface slumping of small ridges left from construction occurred under saturated conditions on the north faces but not on the west faces of dumps and (2) that the snowmelt rate had been lower on west facing slopes than on north facing slopes. However, no quantitative study was done to determine the actual erosion rates and their relation to snowmelt. Other investigators (Gilley and others, 1976; Moody and Bergman, 1976) have studied the erosion effects of rainfall on surface mined slopes. Their findings show that erosion is a function of steepness of slope and length of slope and that certain management techniques such as replanting or reshaping the slope helped to reduce erosion. Burton and others (1978) classified 35 mining waste sites in Utah according to their erosion hazard. They used sediment production from rainfall simulator runs, 2-year, 1 hr. precipitation and mean slope lengths as part of their classification. They found that sites with similar spoils origin, handling of wastes and climate had similar erosion characteristics. Based on their results, it should be expected that wastes from the same formations in the Idaho phosphate area which are similar to each other will have similar erosional characteristics. Similar investigations on agricultural lands have also shown that as steepness and length of slope increase so does the potential for erosion increase (Zingg, 1940; McCool, 1976b; Wischmeier and Smith, 1978).

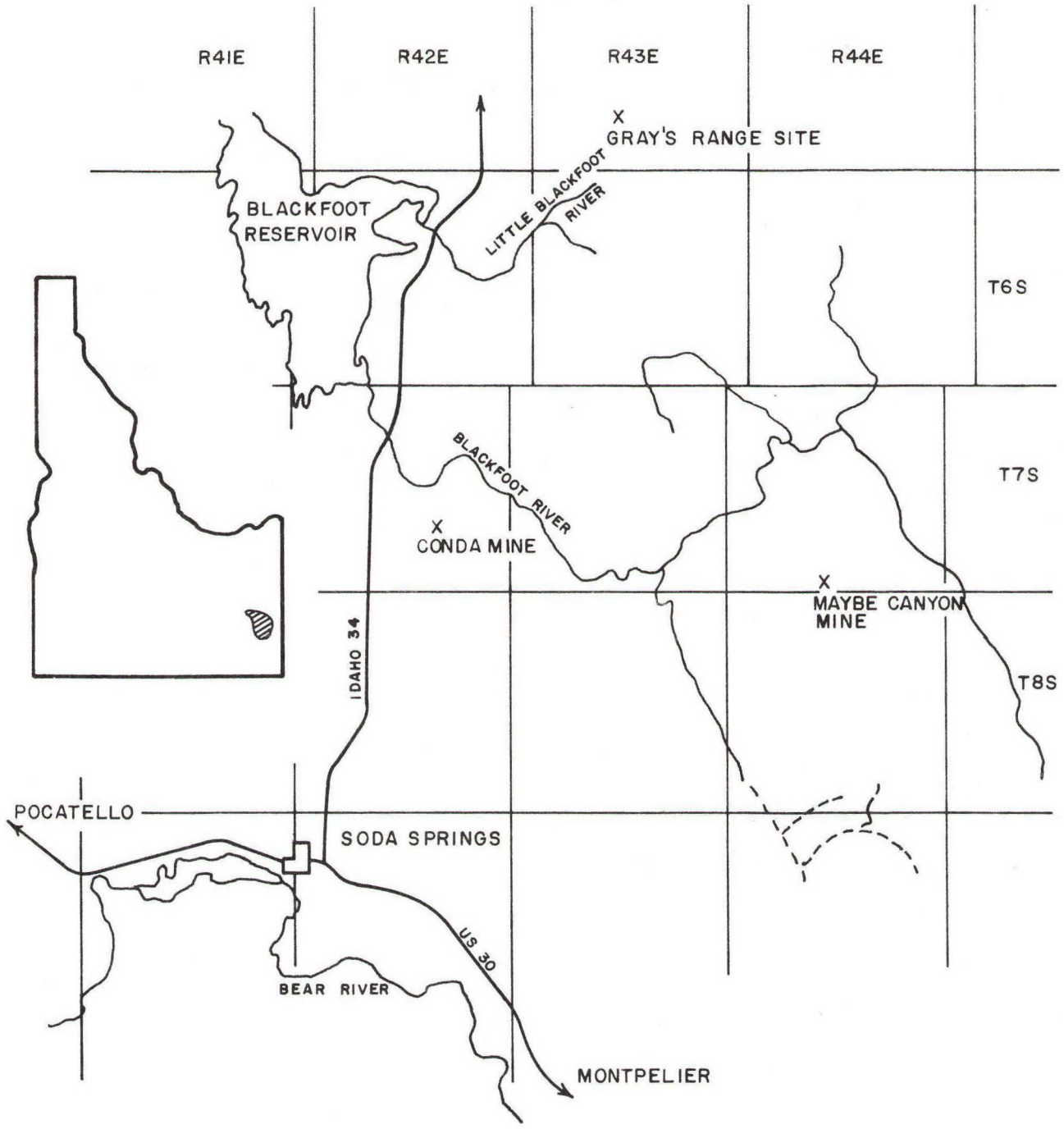


FIGURE 1: Location map of the Idaho Phosphate Region.

The overall topography and weather patterns in the mining region leads to large scale redistribution of snow. However, drift formation can also be greatly influenced on a smaller scale by local topographic changes. The surface mining process with its accompanying waste dumps produces a terrain of mixed slope length and steepness. The slopes are relatively smooth and offer no obstacle to wind, since all vegetation has been removed. However, many terrain breaks are produced in the form of ridges, flattening of slopes and the meeting of slopes of different steepness. Schmidt (1970) and Martinelli (1975) briefly described the process by which certain terrain features can affect the location and size of snow accumulation in the form of drifts. The topographic effects on drift formation have been described by Tabler (1974), Tabler and Johnson (1971), Schmidt (1970) and Martinelli (1975) in their studies of the design and location of snowfence to control drifting snow. Tabler (1975a) has gone a step further and used regression analysis to model drift formation as a function of topography. While this model should be applicable to any area, verification is required before it can be applied to the waste dumps. Tabler (1979) also developed a model for predicting water equivalent and density behind snow fences. The adaptation of this model to waste dump topography would help in erosion prediction.

The management of mine waste dumps from construction to the final stabilized revegetated slope requires a knowledge of the interaction between snow and the waste dumps. The water from melting snow can pose a serious hazard to the stability of the slopes since it is a source of energy for erosion on the waste dump faces. In a wind swept area where drift formations are present the snow water balance includes water lost while the snow is being transported by the wind and water lost from the drift after the snow has been deposited. Sublimation of blowing snow was beyond the scope of this study.

The water lost from a drift seems to be a function of elevation. Rechard (1975) and Rechard and Raffelson (1974) studied the water balance on a snowdrift at an elevation of about 2470 m and reported that about 20% of the moisture was lost to sublimation or evaporation. Beaty (1975) conducted experiments at elevations greater than 3600 m and reported moisture losses of 50-80% to sublimation or evaporation. These studies indicate that the snow in drifts does not behave in the same way as an undisturbed snowpack and that accepted sublimation and snowmelt models should not be applied to drifts without verification.

The division of snowmelt into surface runoff and infiltration requires further study for application to the dump sites. Curtis (1973) has studied the soil moisture relationship on a waste dump in the southeast United States where moisture input occurs primarily in the form of rain. He states that observations of soil moisture on native soils cannot be applied to waste dump conditions. Since the rehabilitation of surface mined areas requires revegetation of the dump sites (Richardson and others, n.d.), the soil moisture and its relation to drift formation are needed.

With these points in mind, the personnel on this project have entered into an agreement with Eugene E. Farmer of the Intermountain Forest and Range Experiment Station in Logan, Utah, whereby the responsibilities of data collection are divided at the ground surface (see Appendix A). The University of Idaho, through this project, is responsible for the collection of meteorological data as well as snow surveys and erosion measurements. Farmer is to measure water below the surface through a network of soil moisture tubes and piezometers.

OBJECTIVES

The objectives of this study can be summarized as follows:

1. Develop a procedure whereby snow accumulation and distribution can be described as a function of vegetation, prevailing winds or storm tracks and size, slope, orientation, and other properties of the waste dumps.
2. Determine amounts of erosion on the waste dumps and relate this to the accumulation and distribution of snow on the dump and the physical properties of the dump such as aspect, slope, and slope length.
3. Determine the rate of ablation of snow, including rate of melt and surface runoff.
4. If possible, through the cooperative efforts mentioned above, perform a rough water balance of the dump.

To carry out these objectives, a number of sites both on and off actual mine dumps were utilized. One dump site was studied in great detail including meteorological data collection, measurement of accumulation and ablation of the snowpack, measurement of erosion and through the concurrent Forest Service study measurement of soil moisture and soil water movement. In addition, a number of other dump sites had snow and erosion data collected. More detailed descriptions of the sites and measurements are given in the next section.

SITE DESCRIPTIONS

It was originally planned to begin the studies on mine dumps in Fall, 1976. Because arrangements could not be completed in time, temporary sites were used to obtain some snow data and to perfect the instrumentation and measurement techniques. These temporary sites were in the Grays Range and at the Conda Mine. The following descriptions of these two sites is quite general because only minimal data were collected there. For more detailed information on site characteristics, see the 1976-77 and the 1977-78 Annual Reports.

Grays Range Site

The Grays Range Site was selected as a temporary site in which to install and test the meteorological instruments and measurement techniques. The site was to be used until a mine dump location was available. With this in mind, a site closely resembling the mine dumps was be desirable. The Grays Range Site, located on a sagebrush and grass covered ridge with a long, even slope of a grade similar to a mine dump (approximately 25 to 33%), was selected (Figure 2).

While the Grays Range Site was not truly representative of the mine dumps as far as topography was concerned, the climatic conditions were similar, providing a suitable testing ground for the meteorological equipment. The equipment used here was of standard National Weather Service design but used with an electronic data logger. The instruments were installed in Fall, 1976, and moved to the Maybe Canyon site in June, 1977. These instruments included thermocouples for measuring air, ground surface and soil temperatures, a heated tipping bucket precipitation gage, nine snowmelt lysimeters, and an aneometer and wind vane. In addition, snow water equivalent and depth at two transects were measured for the three winters of this study.

Conda Mine Site

Three snow transects were established on the Simplot mine near Conda to aid in verifying or modifying Tabler's model of snowdrift profiles and for additional data on snow accumulation and distribution as a function of aspect and topography of mine dumps. The profiles of the three transects are very similar to each other in that each consisted of a steep slope and a flat top (Figure 3). The snowpack was measured in mid-January and mid-March, 1977. No meteorological instrumentation was installed at this site since there was a weather station at Conda. This site was abandoned in Spring, 1977, when it became apparent that there would not be enough time to make all the necessary measurements on the Maybe Canyon dumps and the Conda dumps as well.

FIGURE 2: Grays Range windward slope of snow transects.

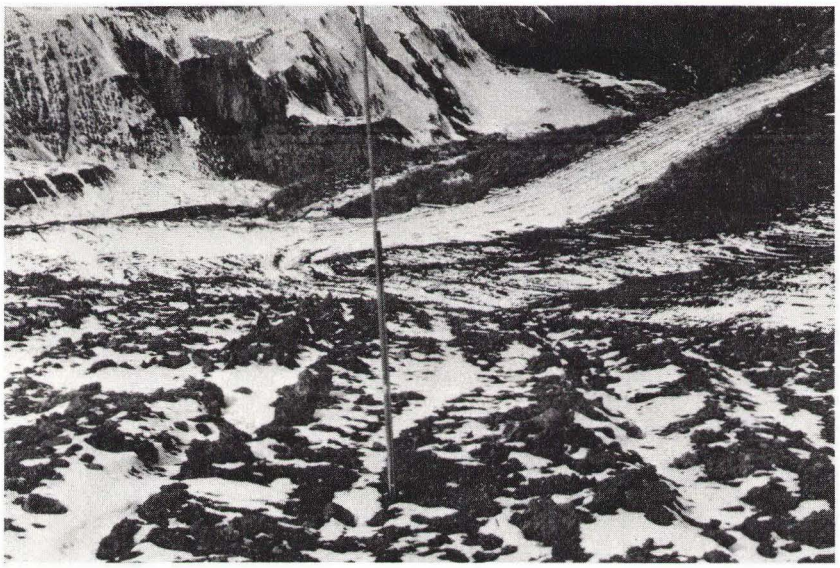


FIGURE 3: Conda Mine Snow Transect 1 in March 1977 showing existing snow cover.

Maybe Canyon Site

This site consisted of eight mine dumps located near a temporarily abandoned mine pit. Figure 4 shows the location of eight dump sites in relation to the mine pit. Dumps 2, 6, 7 and 8 were selected for both the snow and erosion study while Dump 5 was used for the snow study only. The basic criterion for the selection of dumps for erosion measurements was the date of completion of the dumps. Dumps 2, 6 and 7 were completed in the fall of 1976, the year the study began, and were selected so that erosion measurements could be made at age one year and continue annually for the duration of the study. Dump 8 was completed one year later, in the fall of 1977. The remaining dumps (1, 3, 4 and 5) were completed in 1964, 1977, 1972 and 1974 respectively.

Three of the study sites, Dumps 6, 7 and 8, are very similar in size and shape. Each was constructed with a long, uniform slope with no breaks from top to bottom. Typically the slopes are about 40-45 per cent and the slope length 300-400 m. The three dumps are also located adjacent to one another. Thus, the only major difference between the dumps is the aspect of the dump face, which ranged from southerly to nearly due West (178 to 276°). The remaining study site, Dump 2, has considerably different size and shape. The dump is much shorter with slope lengths ranging from 60 to 125 m and is less steep with a slope of about 26 per cent. The dump face is also bowl-shaped resulting in a difference in aspect of about 50° from one side to the other, with the general direction being North. The topographical data are summarized in Table 1 and maps are shown in Figures 5 to 9.

METHODS

Three basic types of measurements were made. These were meteorological measurements, snow (depth and water equivalent) measurements and erosion estimates.

The meteorological station was initially installed at the Grays Range Site in Fall, 1976, and then moved to Dump 2, Maybe Canyon Mine, in June, 1977. This station consisted of sensors connected to an electronic data logger. The data logger had a magnetic tape output and a printed paper tape backup. The sensors measured the following:

1) Precipitation: a heated tipping bucket gage with wind shield.
2) Temperature: a thermocouple in the air, at the soil surface and at two depths in the soil. Temperature was averaged over a three hour period.
3) Wind run: distance over a three hour interval.
4) Wind direction: eight directions were recorded.

TABLE 1: Topographical data for the mine dumps.

Site	Slope (%)	Length (m)	Aspect (°)	Area (ha)
Dump 2				2.3
Transect 2	23	122	327	
Dump 6				5.7
Transect 1	48	311	178	
Transect 2	48	354	199	
Dump 7				6.2
Transect 1 erosion	40	393	208	
Transect 2 erosion	42	366	235	
Transect 1 snow	48	364	194	
Transect 2 snow	56	351	226	
Dump 8				5.0
Transect 1 erosion	41	205*	249	
Transect 2 erosion	43	144*	254	
Transect 1 snow	55	268	243	
Transect 2 snow	47	297	276	

* To the top of the slump only

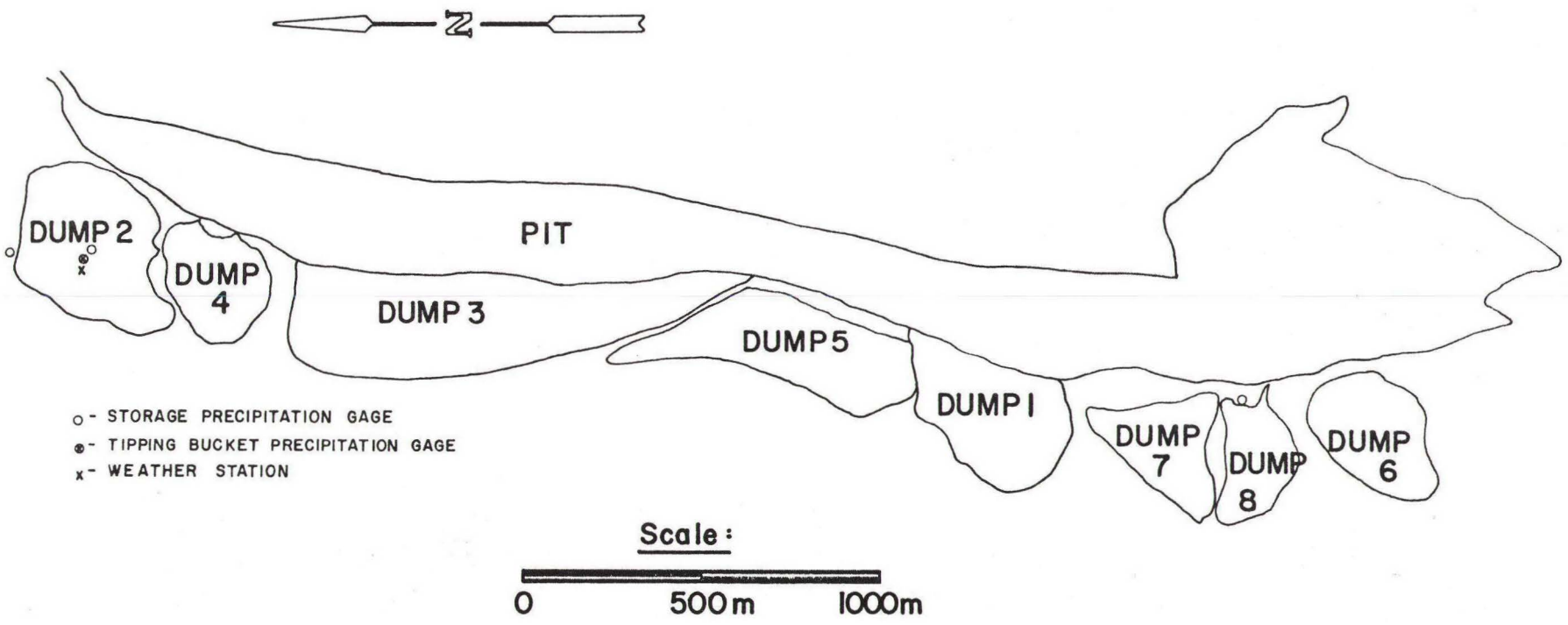


FIGURE 4: Map of the mine showing the relative location of the waste dumps.

5) Snowmelt lysimeter: a one meter square pan was installed but it functioned properly only during part of the 1979 winter due to rodent damage.

6) Relative humidity: averaged over a three hour period. This was collected only during the 1978-79 winter.

In addition, three shielded storage precipitation gages were installed. One was at the top of Dump 8, one next to the tipping bucket gage at the top of Dump 2 and one at the bottom of Dump 2 (Figure 4).

The snow data collected consisted of depth and/or snow water equivalent on straight line transects. Each transect consisted of enough points so that the profil of the drift or the total water on a transect could be determined.

Two transects were measured three winters on Grays Range while the three transects established on the Conda Mine were measured only during the 1976-77 season.

Snow transects were established at all study sites on the Maybe Canyon Mine. These are shown on the dump maps (Figures 5-9). There were two each on Dumps 6, 7 and 8 which approximately corresponded in location to the erosion transects and three transects each on Dump 5 and the ridge to the southwest of Dump 2. These all were measured several times during the 1977-78 and 1978-79 seasons. In addition to these transects, the complete snow cover over Dump 2 was mapped using the 23 m square grid established for the soil moisture tube network. No map is available for Dump 5.

The depths and snow water equivalents were measured using a Federal Snow Sampler. In the drift areas where the snow depth exceeded the sampler length, a depth probe was used. The snow water equivalent was then estimated from density measurements obtained from other sample points on the drift. This caused little error because the densities in any one drift were fairly uniform.

The erosion measurements were made using the rillmeter shown in Figure 10 (McCool and others, 1976). This instrument provides a photographic record of the ground surface profile of a 1.83 m section. The photo is enlarged to approximately 450 mm wide and analyzed to give a measurement of soil loss as a function of rill area on the photo. Depending on the reference point used in the field, different types of erosion can be measured. The two types of reference used in this study were:

1) Ground Reference - where the instrument is placed directly on the ground and measures only rill or gully erosion.

2) Pen Reference - where the instrument is placed on permanently installed 1.5 m long steel pins which are surveyed for location and elevation and measures total soil loss (both rill and sheet erosion).

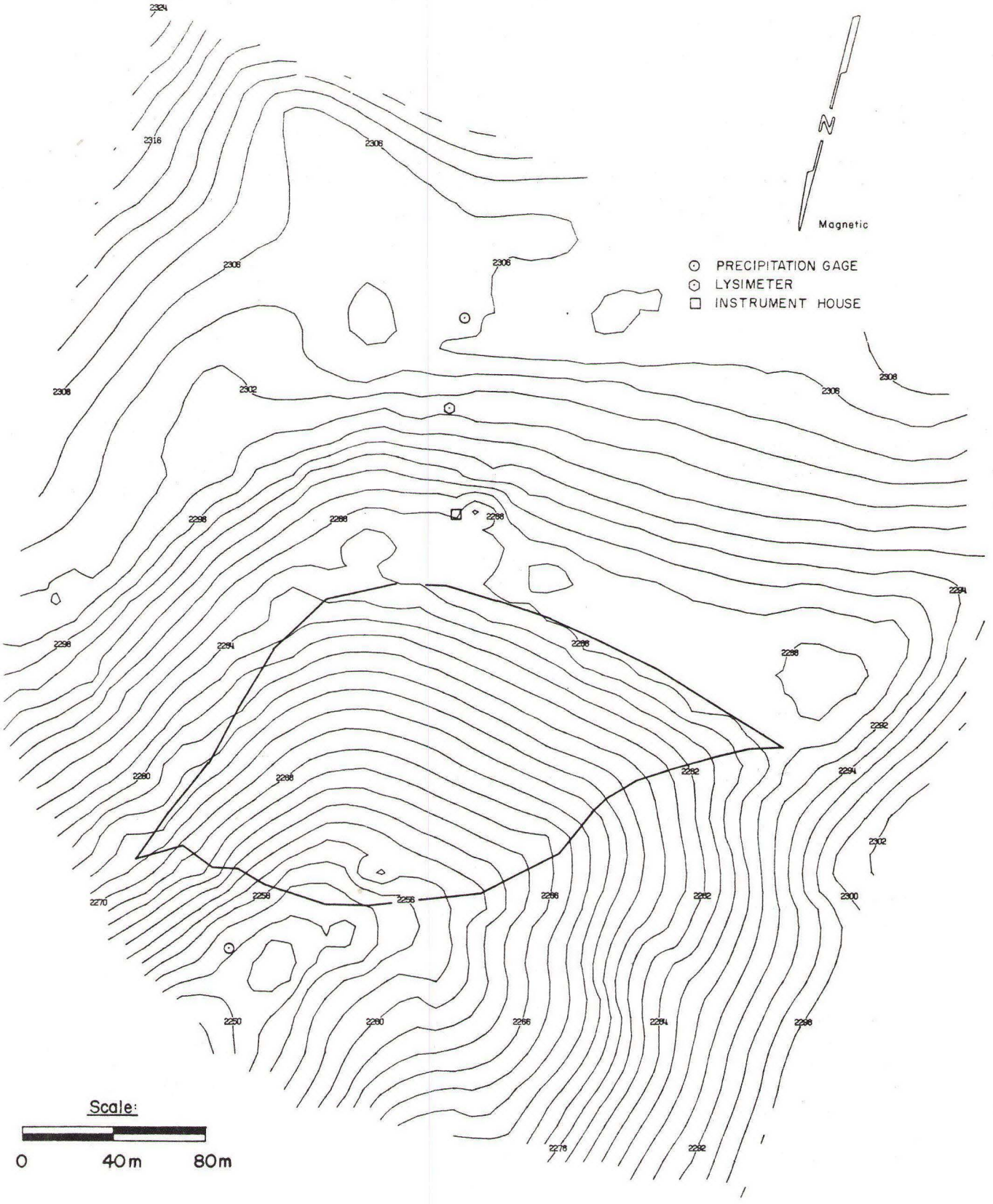


FIGURE 5: Map of Dump 2. Outlined area is the intensive study site.

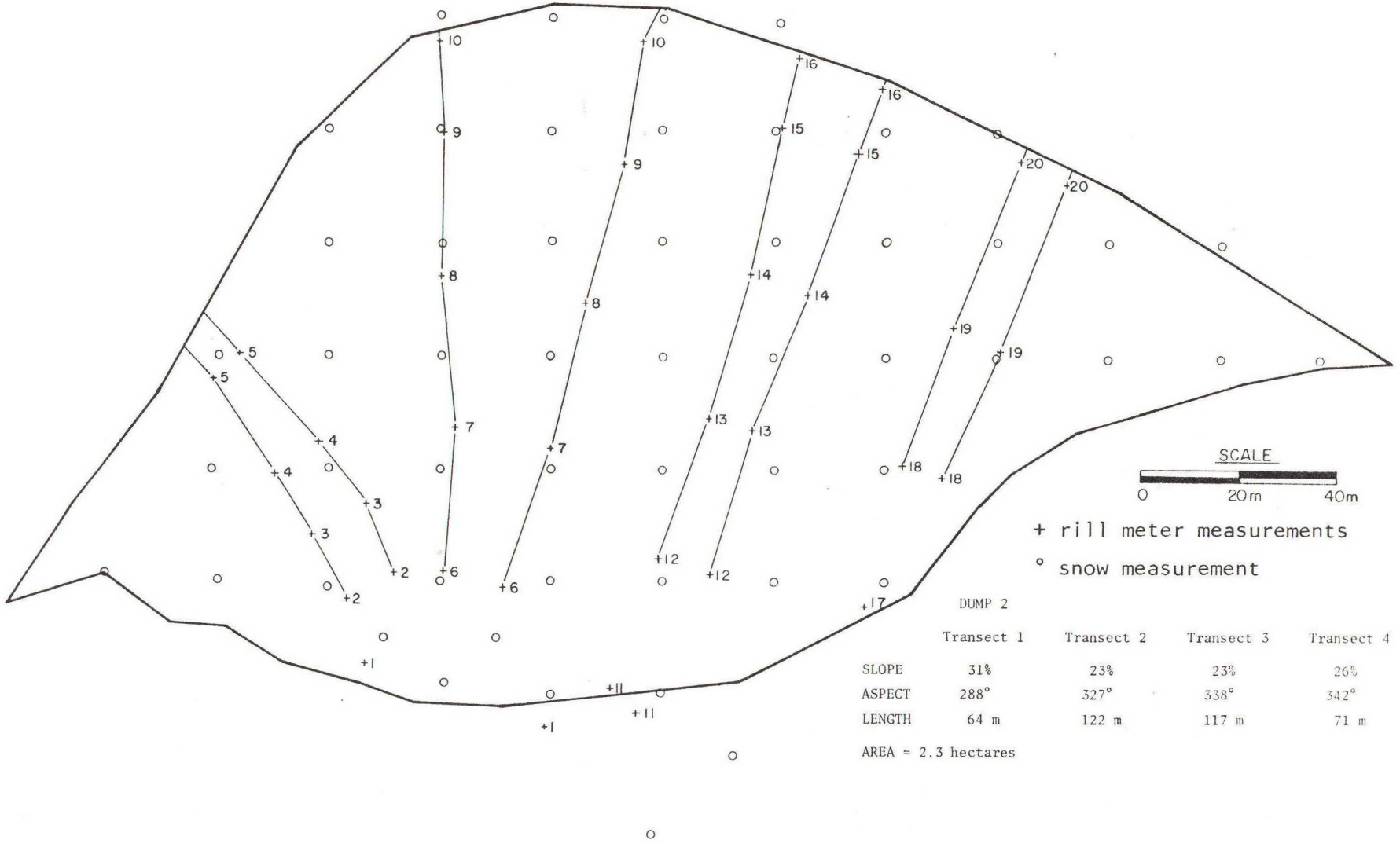


FIGURE 6: Map of Dump 2 showing location of erosion and snow measurement sites.

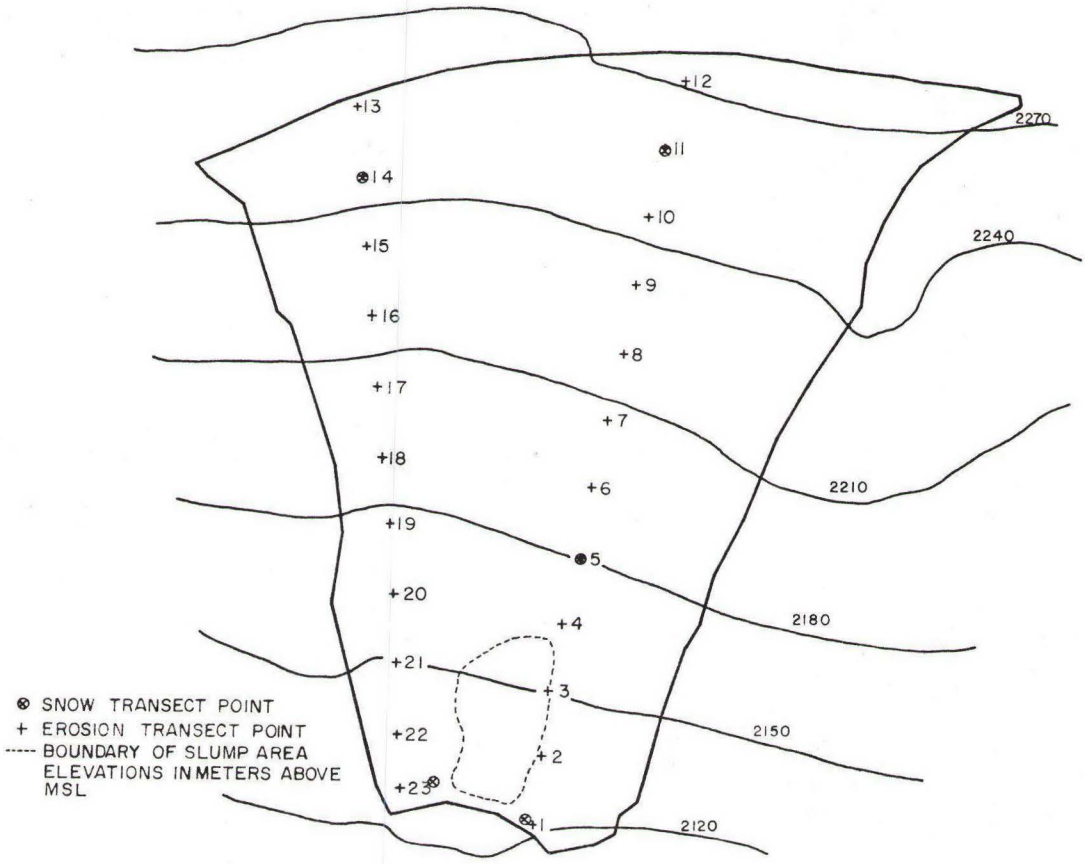


FIGURE 7: Map of Dump 6 showing location of snow and erosion measurement sites.

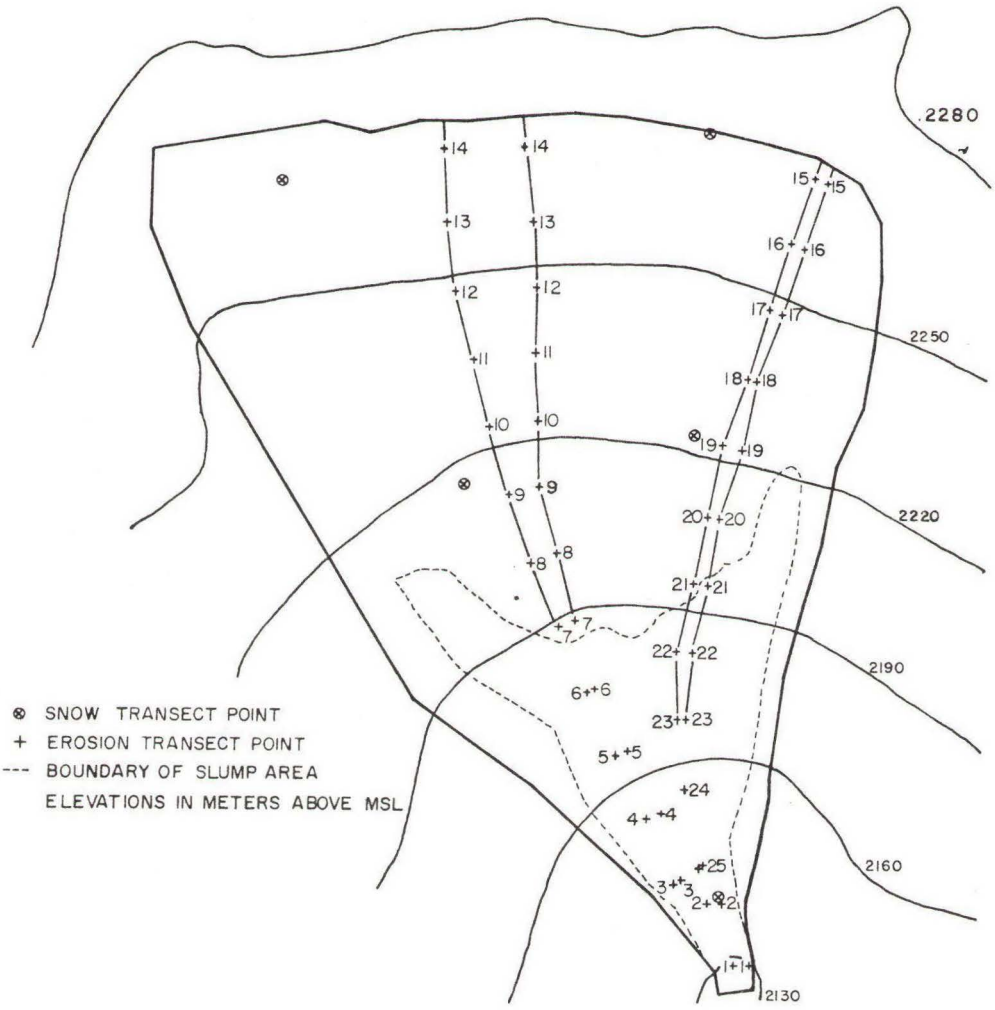


FIGURE 8: Map of Dump 7 showing location of erosion and snow measurement sites.

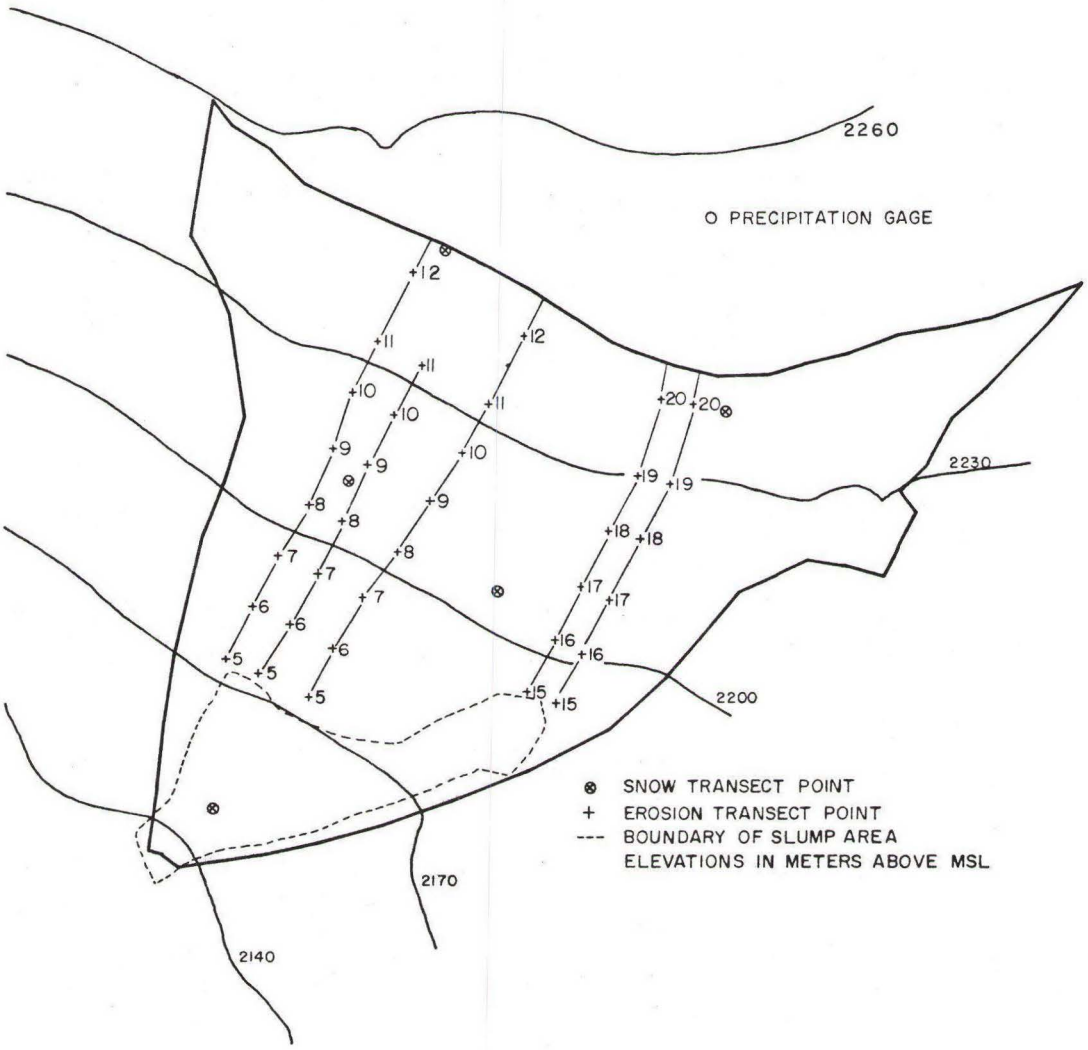


FIGURE 9: Map of Dump 8 showing location of erosion and snow measurement sites.

The first method is quite subjective in that the location of the original ground line must be estimated. The second method depends upon the accuracy of the measurement of the pin elevation and the stability of the soil.

The initial set of measurements was made in September and October, 1977 on Dumps 2, 6 and 7 and represented the rill erosion occurring in the first year after completion of the dumps. All three dumps were measured using the ground reference technique. In addition, the pin reference technique was also used on Dump 2. The second set of measurements was made on the same dumps in July, 1978 along with the initial measurements on Dump 8. The final set of measurements was made in June, 1979 on all four dumps.

The approximate one year interval between measurements provided total annual erosion from all sources. However, due to the patterns of precipitation it is assumed that the major portion of any erosion is due to snowmelt runoff only.

EROSION RESULTS

Introduction

Dumps 6, 7 and 8 are very similar in size and shape. The erosion measurements were made nearly identically on these three dumps. The measurements were made starting at the top of the slope and continuing downslope at approximately 30 m intervals on two transects. The location and spacing of the measurement sites are shown on the maps of each dump in Figures 7 to 9.

On Dump 2, the site of the intensive study, the erosion measurements were made in a similar manner except that four transects were established on the lower dump face (Figures 6 and 11).

On Dumps 2, 7 and 8, the rill pattern was sufficiently distinct that the rill drainage areas could be determined. Therefore, on these dumps the erosion was measured across the entire rill drainage at each site. The lines drawn between the measurement points in Figures 6, 8 and 9 indicate the drainage areas selected. Using this method, erosion amounts can be determined as a function of drainage area. The rills were not so obvious on Dump 6, and it was impossible to determine rill drainage areas although an attempt was made to extend the width of measurements at each site across drainage boundaries even when the boundaries were not very apparent. For this reason, the erosion rates versus drainage area have not been computed for Dump 6.

Dumps 6, 7 and 8 experienced mass wastage in the form of surface slumping sometime during the spring of 1978. The slumping on Dump 6 was relatively minor and affected only two of the erosion measurement sites. The slumping on Dumps 7 and 8 was much more extensive eliminating nearly half the erosion sites.

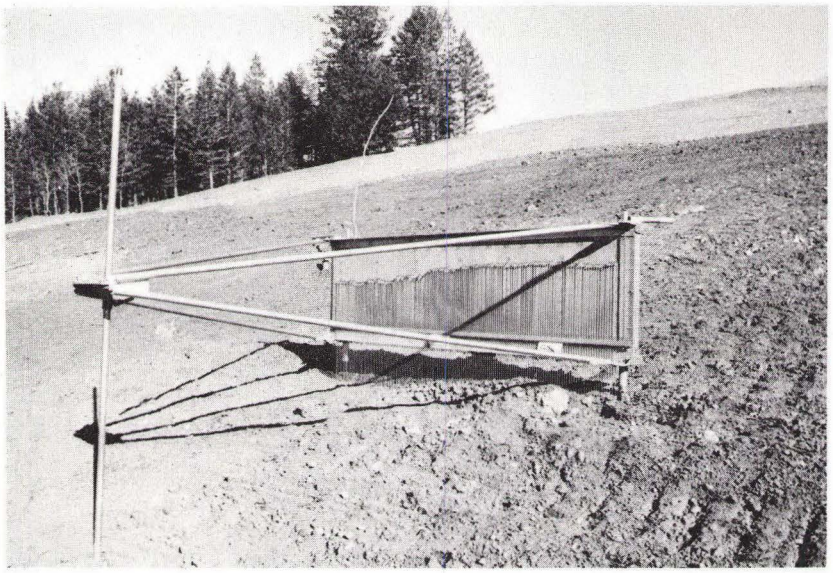


FIGURE 10: Rillmeter used in erosion measurements.

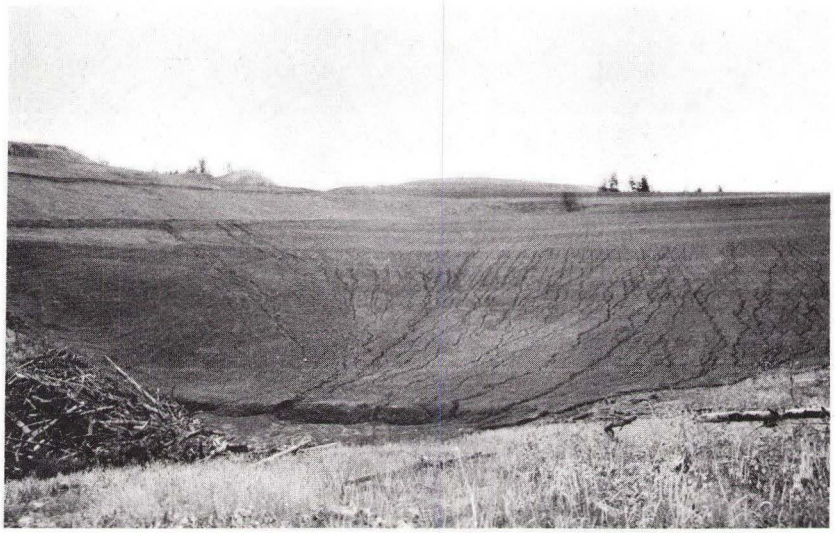


FIGURE 11: Maybe Canyon Mine Dump 2, the site of intensive study.

Graphs of slope-length and erosion relationships were prepared in an attempt to derive an understanding of the effect of long slopes on erosion amounts. These are discussed first and then followed by a discussion of the effect of rill drainage and erosion.

Slope Length

Dump 2 The size and shape of Dump 2 is considerably different from that of Dumps 6, 7 and 8. This can be readily seen by comparing Figures 5 through 9. The dump was completed in the fall of 1976 and the first erosion measurements were made in the summer of 1977.

The plot of average erosion at each site as a function of slope length is shown in Figure 12 for 1977 only. With the exception of Transect 1, the general shape of the curves is similar. The explanation for this difference for Transect 1 is that the erosion on this transect was due to the breakdown of a drainage berm around the top of the dump which resulted in the drainage of water over the dump.

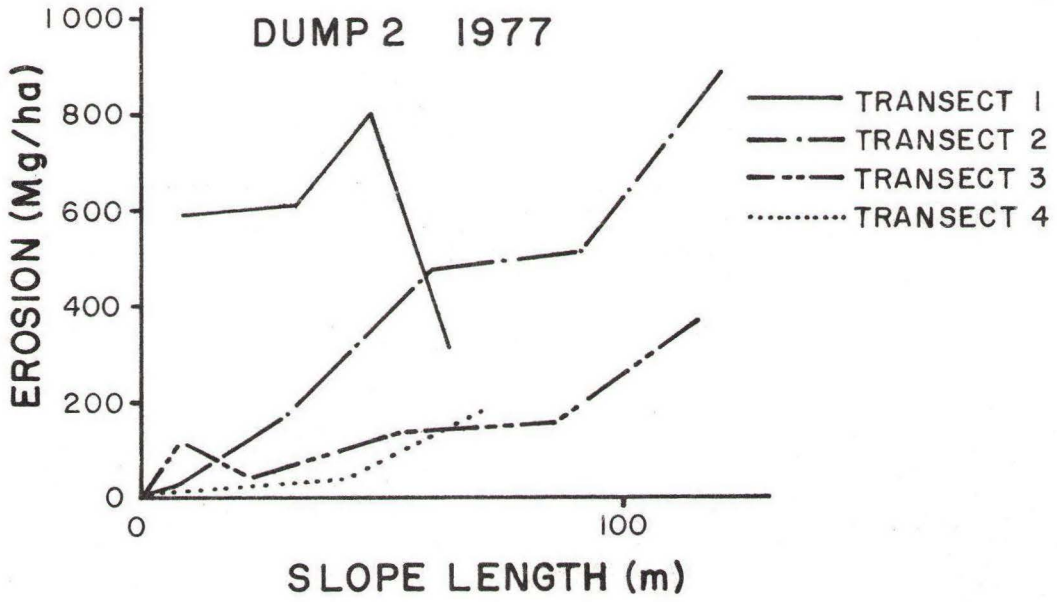


FIGURE 12: Erosion as a function of slope length - Dump 2, 1977.

In the fall of 1977, due to the requirements of the concurrent Forest Service study on this dump, the dump face was regraded, eliminating the major rill formation. At this time Transects 1 and 3 were reestablished to measure total erosion

using the previously described pin reference technique. The initial pin measurements were made in the fall of 1977 with succeeding measurements made in the summer of 1978 and 1979, along with the other erosion measurements.

The pin reference data is not reported here due to problems with the measurement technique. The basic criterion of this technique is the stability of the reference pins. Although the pins used here were 1.8 m long, there was movement of the pins in relation to the ground surface. The movement was detected by surveying the tops of the pins each year. Some of the pins gained elevation, which can only be explained by frost heaving. Many of the pins lost elevation which was due to differential settling of the dump surface. Supportive evidence of this were the large depressions, which in one case approached what might be termed a sinkhole, which formed in various areas of the dump. In addition, large cracks appeared in the dump surface indicating some movement of the dump material. In any case it appears that the instability of the new dump surfaces is not conducive to the use of this measurement technique.

The remaining two transects, 2 and 4 were measured using the ground reference technique in 1978 and 1979. The data for Transect 2 (Figure 13) show there was a substantial reduction of the erosion in 1978. Note that this is not a total erosion measurement for two years, since the dump surface had been regraded in the fall of 1977. However, even though there was a reduction in measured erosion in 1978, the general shape of the curve is similar. The data from 1979 indicate that there was not an increase in erosion for the third year and, in fact, some filling in or smoothing of the rill formation may have occurred at about mid-slope.

Transect 4 was a small area on the west edge of the dump. The data in Figure 14 show that there was not a large differential of erosion on this transect for any year.

Dump 6 Dump 6 was measured one time each in the summers of 1977, 1978 and 1979. The measured erosion as a function of slope length is shown in Figure 15 for both transects. The 1977 data should represent the total rill erosion for the first year of the dump life. The 1978 data should represent the total erosion for the first two years of dump life and the 1979 data, the total erosion for the first three years of dump life. Therefore, without the interference of some external factor, such as regrading, the erosion for each successive year should increase with the differential between any two years representing the erosion occurring during one year. As seen in Figure 15 the measurements do not show this.

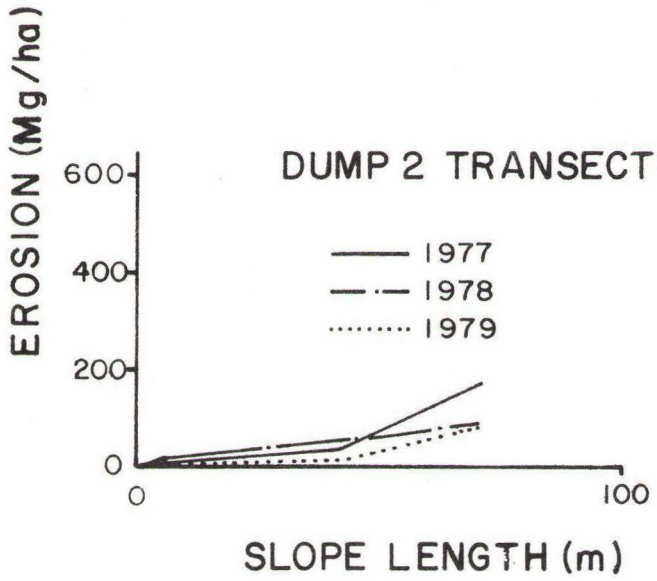


FIGURE 13: Erosion as a function of slope length - Dump 2, Transect 4, 1977-79.

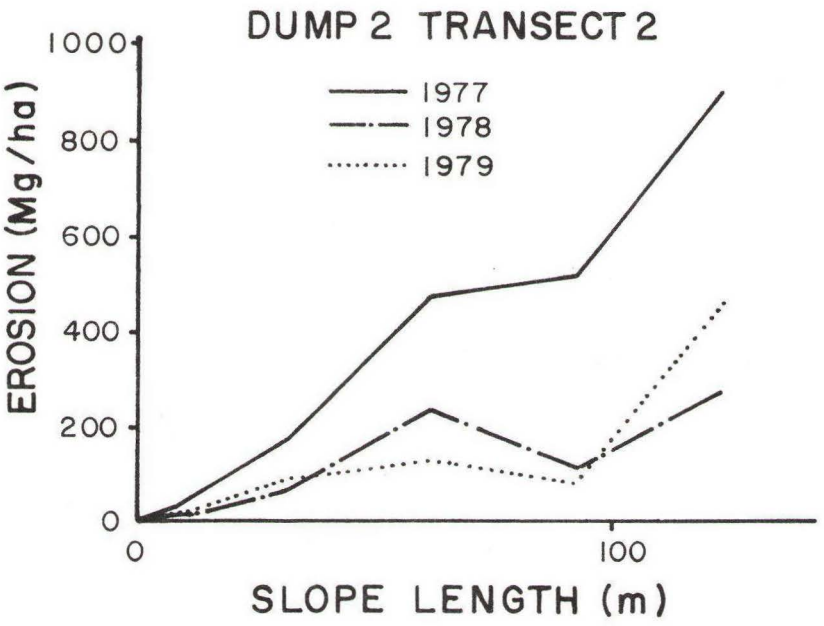


FIGURE 14: Erosion as a function of slope length - Dump 2, Transect 2, 1977-79.

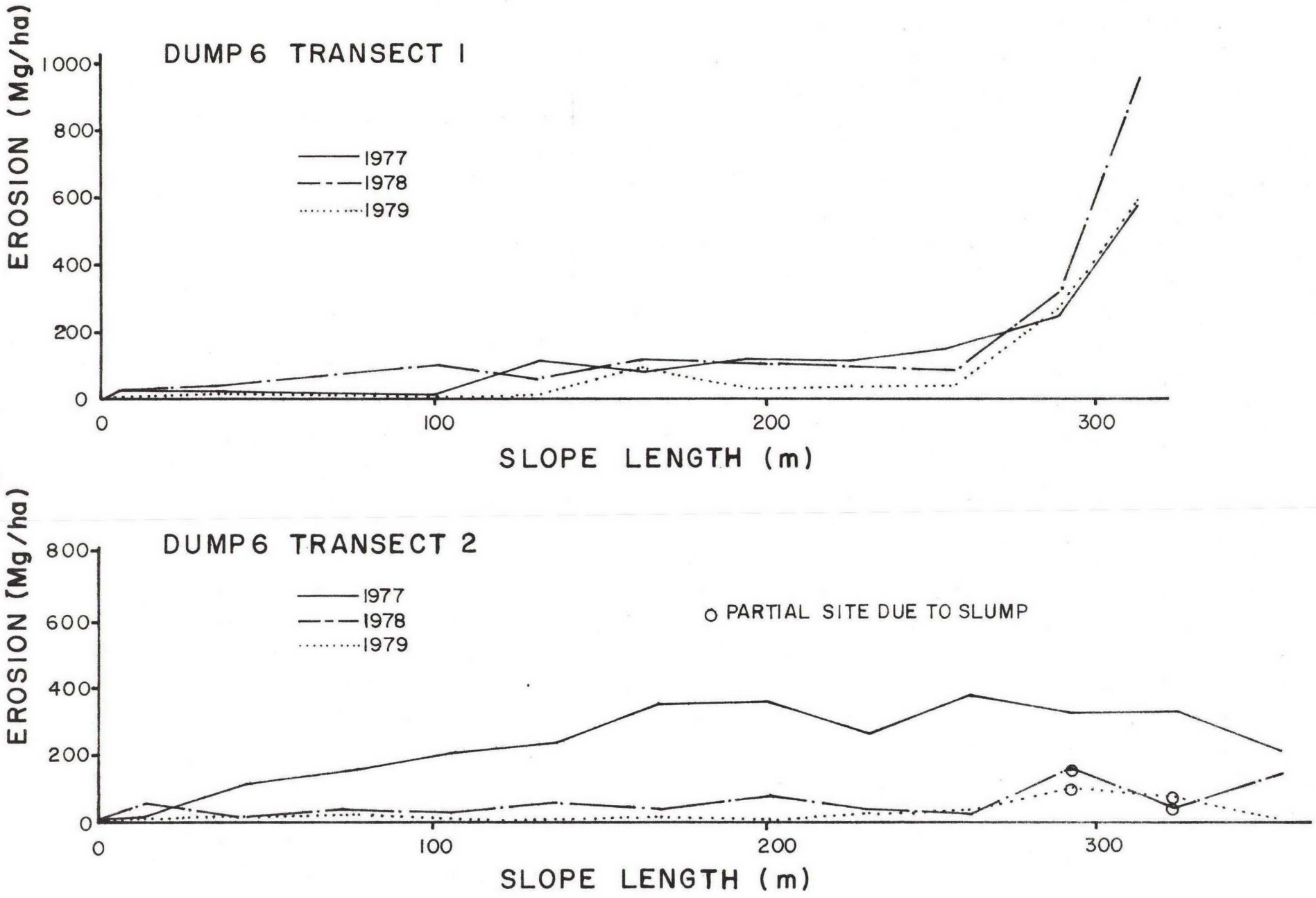


FIGURE 15: Erosion as a function of slope length - Dump 6, Transects 1-2, 1977-79.

The most obvious difference occurred on Transect 2, particularly with the 1977 data. There is no good explanation for the high values determined in 1977. The 1978 and 1979 data are very nearly equal and are near the lower limits of the rillmeter detection capability. If the two sites affected by the slump are ignored, there is nearly uniform minimal erosion from top to bottom in both 1978 and 1979. Since the 1978 and 1979 data are so similar it must be assumed that the 1977 data are not a true representation of gross erosion and that the erosion for three years on this transect was so low that it strained the capabilities of the measurement technique.

The data from Transect 1 appear to be more representative (Figure 15). While the differentials between successive years are still not apparent, the data from all three years follow the same trend and are nearly equal for each successive year. The conclusion that can be drawn is that a minimal amount of erosion was detected over most of the slope length until a slope length of about 260 m was reached when there was a significant increase in erosion from that point to the bottom of the dump. Again little can be said for the annual differential, but the same increase with length was detected in the three sets of measurements, indicating that most, if not all, the erosion past the 250 m point occurred in the first year. This is borne out by qualitative field observation which showed that much of the erosion occurred during the first year before vegetation was fully established.

Dump 7 Dump 7 was completed in the fall of 1976, enabling three sets of erosion measurements to be made. During the first year there was extensive rill erosion which resulted in two types of rill patterns (Figure 16). On the left side of the dump (Transect 1) the rills formed a dendritic pattern while on the right side (Transect 2) the rills ran parallel to one another for nearly the entire length of the dump.

During the second year, near the end of the snowmelt season, extensive slumping took place which removed the surface material of the bottom portion of the dump to approximately sites 7 and 21. This eliminated nearly half of the erosion measurement sites (Figure 8).

In response to the slumping, the mining company enacted a slump prevention program in the summer of 1978. This involved placement of a drainage ditch at the upper limit of the slump with perforated pipe and stand pipe placed in the bottom of the ditch. The purpose was to drain surface and intercepted subsurface water off the dump at this point. In addition, a series of strips was constructed on the contour from the dump top to the drainage ditch in which the ground surface

FIGURE 16: Maybe Canyon Mine Dump 7.

was ripped to intercept surface runoff. The slumped area was resurfaced and reseeded.

The results of the erosion measurements on Transect 1 are shown in Figure 17. If the last site is ignored due to influence of the slump area, the 1978 data show a nearly uniform increase over the 1977 data. The 1977 data represent the rill erosion from the first year. The 1978 data represent the total rill erosion for two years. The difference between 1978 and 1977 lines represents the rill erosion during the second year. The 1979 data should represent the total rill erosion for three years. At no point does the 1979 data exceed the 1978 data. If there were no erosion during the third year, the 1979 data should overlay the 1978 data. Since the 1979 erosion amounts are less than the 1978 amounts, what was measured was a reduction in rill cross-sectional area. This could conceivably occur in two ways: one is that extensive sheet erosion took place, lowering the elevation of the ground reference point of the rillmeter relative to the bottom of the existing rill. This explanation can be discounted in this case, since sheet erosion of that extent would be obvious in the dump's appearance. The other explanation is that the rills became filled in. This is a plausible explanation since at some sites obvious filling had taken place due to material moving off the ripped areas and settling in the rills.

With the exception of one point, the 1978 Transect 2 data are nearly identical to the 1977 data (Figure 18). This indicates that if erosion did occur, it was less than that which could be detected by the measurement technique employed. The same is true of the 1979 data with the exception of one site where obvious filling in of the rill had occurred. This lends some additional support to the hypothesis proposed for Transect 1.

Dump 8 The erosion measurement method on Dump 8 was very similar to Dump 7 except that the dump was not completed until the summer of 1977 so that only two years data were collected. Also like Dump 7, the bottom portion of this dump experienced extensive slumping in the spring of 1978. The slumping eliminated the erosion measurement sites near the bottom of the dump, essentially cutting the slope length nearly in half. The erosion data are plotted in Figure 19.

The erosion on Transect 2 was negligible. This was in agreement with field observations, where very little rill erosion was noticeable over the measurement area.

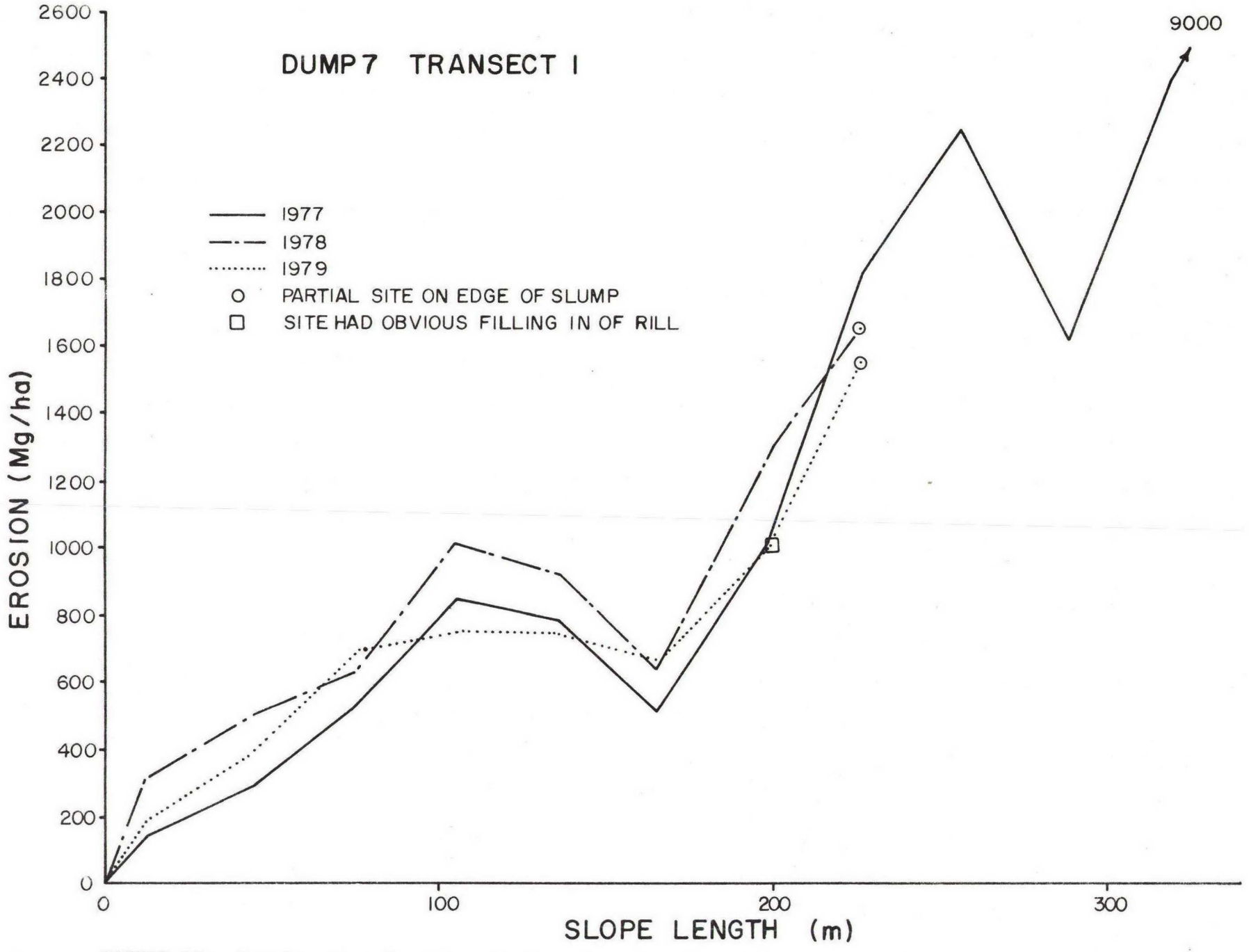


FIGURE 17: Erosion as a function of slope length - Dump 7, Transect 1, 1977-79.

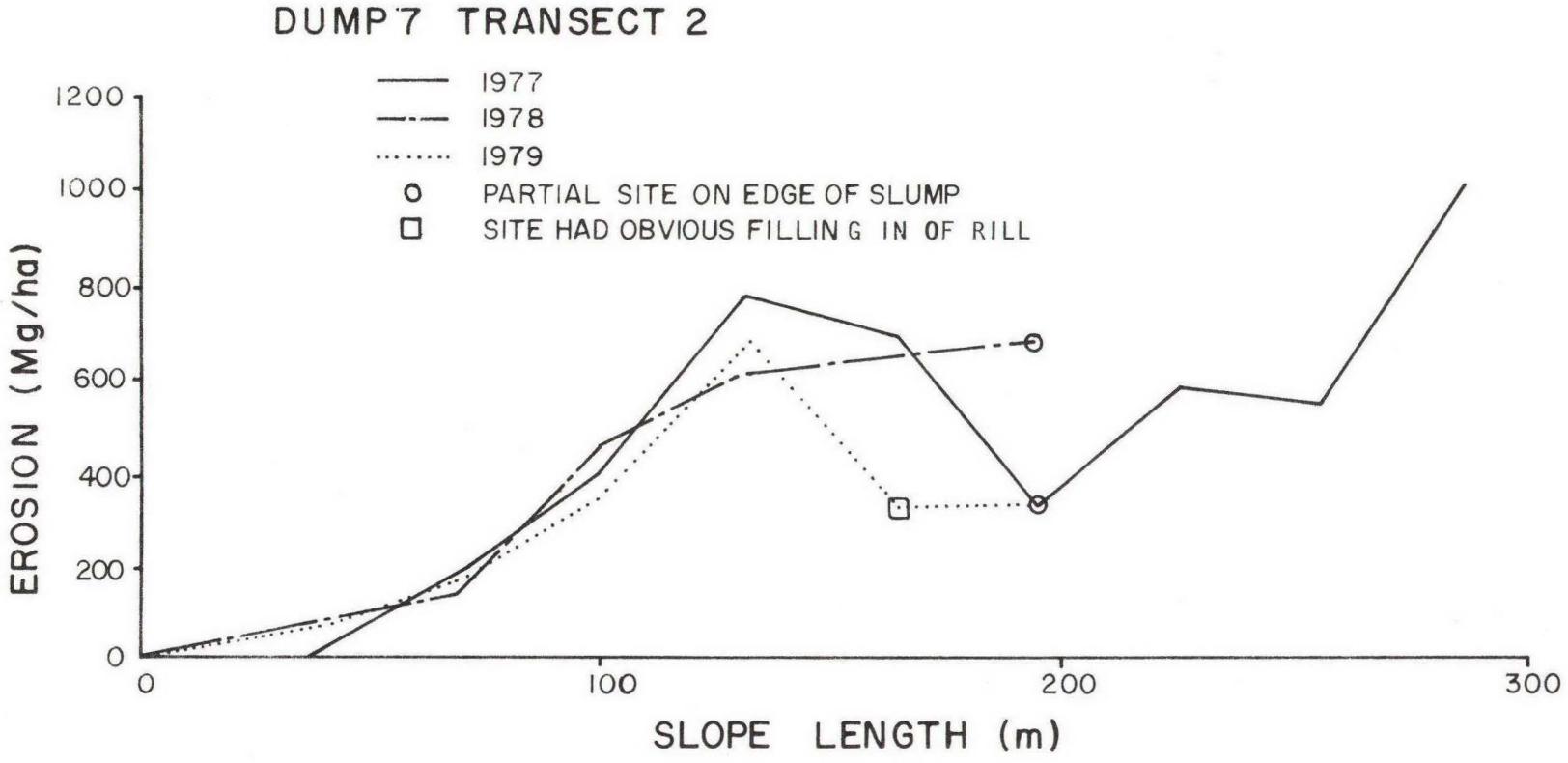


FIGURE 18: Erosion as a function of slope length - Dump 7, Transect 2, 1977-79.

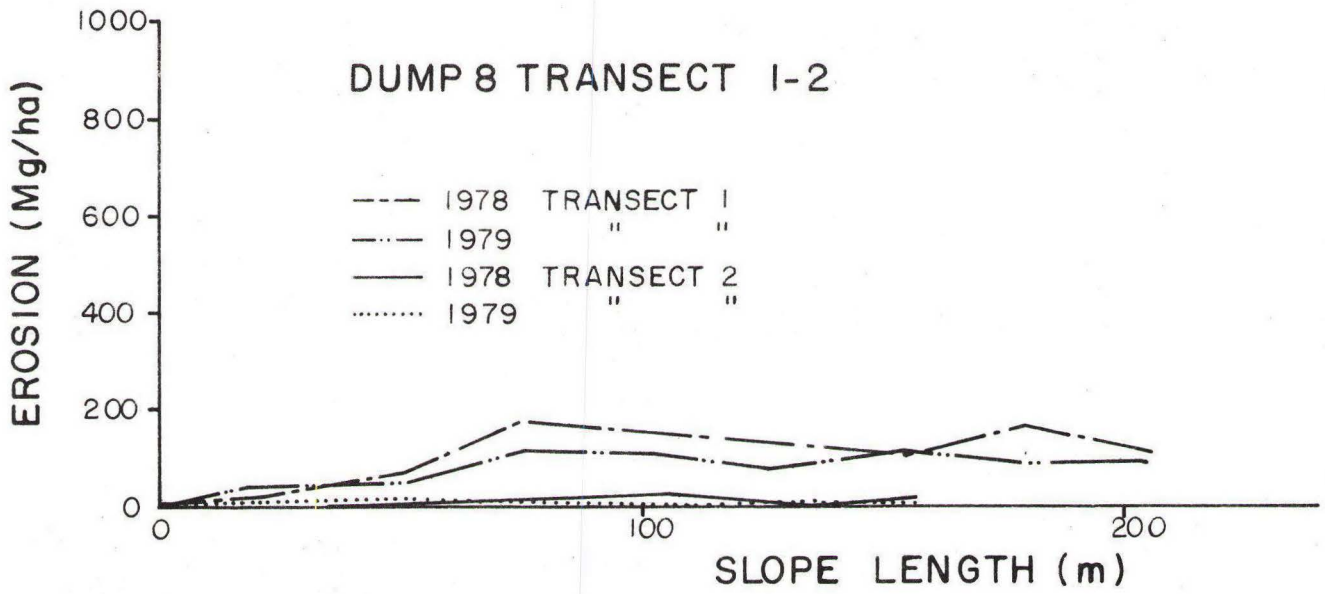


FIGURE 19: Erosion as a function of slope length - Dump 8, Transects 1-2, 1978-79.

The area encompassing Transect 1 had visible rill development. The rill erosion differed from that of Dump 7 in that, although there were many rills, the cross-sectional area of each rill was relatively small and was approximately square in shape. The rills of both transects on Dump 7 were much larger and rectangular shaped with the depth much larger than the width. The rill formation pattern on Dump 8 more closely followed the parallel rill pattern as found on Dump 7, Transect 2.

The magnitude of the erosion on Transect 2 is much less than that of Transect 1. In both 1978 and 1979, the erosion amount on Transect 1 rose to a plateau and then remained relatively constant for the rest of the slope length. There is no apparent reason for the type of differences found between 1978 and 1979. A possible explanation is that the negative change in 1979 is within the error of the measurement procedure. In any case, the conclusion is that there was not significant erosion between the summer of 1978 and 1979.

Drainage Area

The analysis of erosion as a function of drainage area was done on Dumps 2 and 7. On Dump 7 the rill pattern was well established the first year and the rill drainage area did not change during the next two years. On Dump 2 the dump face was regraded after the first year and the rill pattern was not reestablished as extensively and as deeply as before resulting in a slight change in drainage year area for the three years of measurement. On Dump 8, the erosion sites were

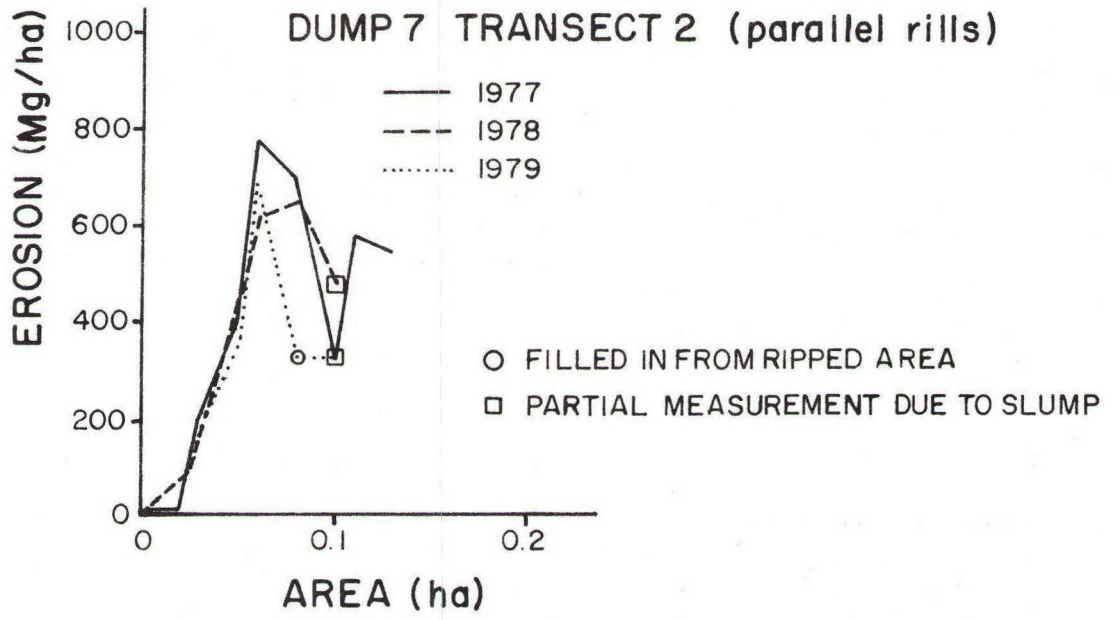
also established across rill drainage areas but due to the very low erosion on these sites no analysis was made.

Dump 7 Since the rill drainage area did not change during the study the erosion measured on each transect shows the same relative differential as when plotted against slope length (Figure 20). The same reasons given for the relationships in the slope length section of this paper are also appropriate here. The significance of this analysis on Dump 7 is the large difference in the shapes of the curves for each transect. This difference was not seen in the slope length analysis where the curves for the two transects were much better matched. The reason for this difference is the type of rill pattern represented by each transect. As previously mentioned, Transect 1 represents an area of dendritic patterned rill formation while Transect 2 represents parallel rill formations. While the parallel rill pattern results in a small drainage area for a given slope length it also results in higher erosion per unit area as a function of drainage area.

On both transects there is a reduction in erosion near the 80 percent drainage area corresponding to an area of 0.4 and 0.1 hectares for Transects 1 and 2 respectively. This same reduction was seen in the slope length analysis (Figures 17 and 18) at about the 180 m mark or halfway down the slope. A similar reduction in erosion was observed on both sides of the dump at the same level. Apparently at this location on the dump there is some variation in the composition or structure of the dump. A possible explanation is that this is a result of dump construction technique. This dump was formed by pushing material down the dump face to about the middle of the dump from which point it was allowed to roll to its angle of repose. This technique may result in the material at the middle of the dump becoming more consolidated and therefore more resistant to erosion.

Dump 2 The plots of erosion versus drainage area for Dump 2 are shown in Figure 21. Note that in 1977 four transects were measured while only Transects 2 and 4 were measured after that. Also with the exception of Transect 1, 1977, the curves have very similar shapes for the transect drainage area. The explanation for the difference in Transect 1 has been stated in the slope length analysis section where this same type of difference was observed, providing evidence that the quantity and flow path of surface water is a major factor in determining erosion.

The results of erosion measurements on Transect 2 show a similar pattern of reduced erosion from year to year. The major reduction occurs after the first year after the dump face had been regraded. This can be attributed only to one



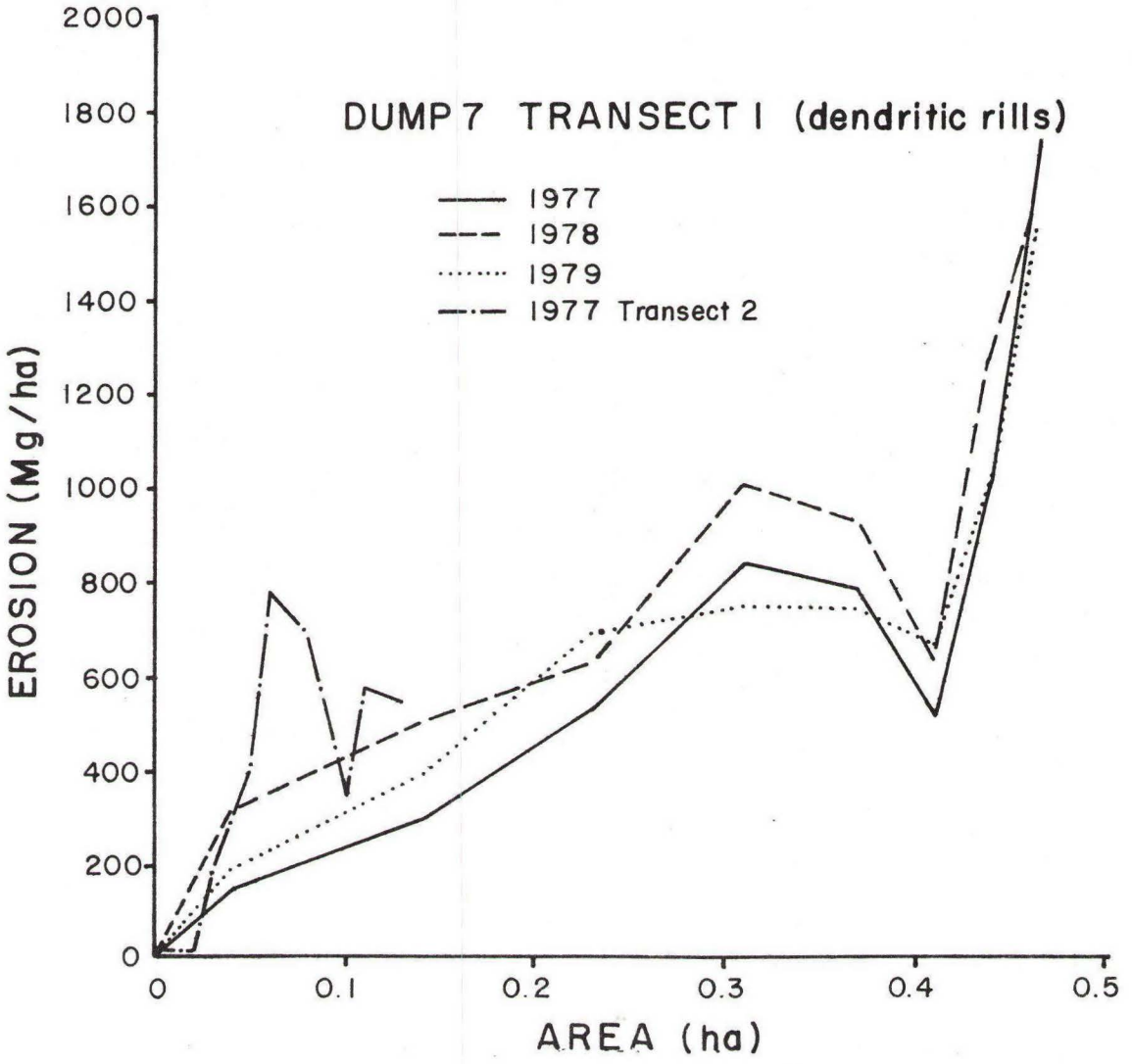


FIGURE 20: Erosion as a function of rill drainage area - Dump 7.

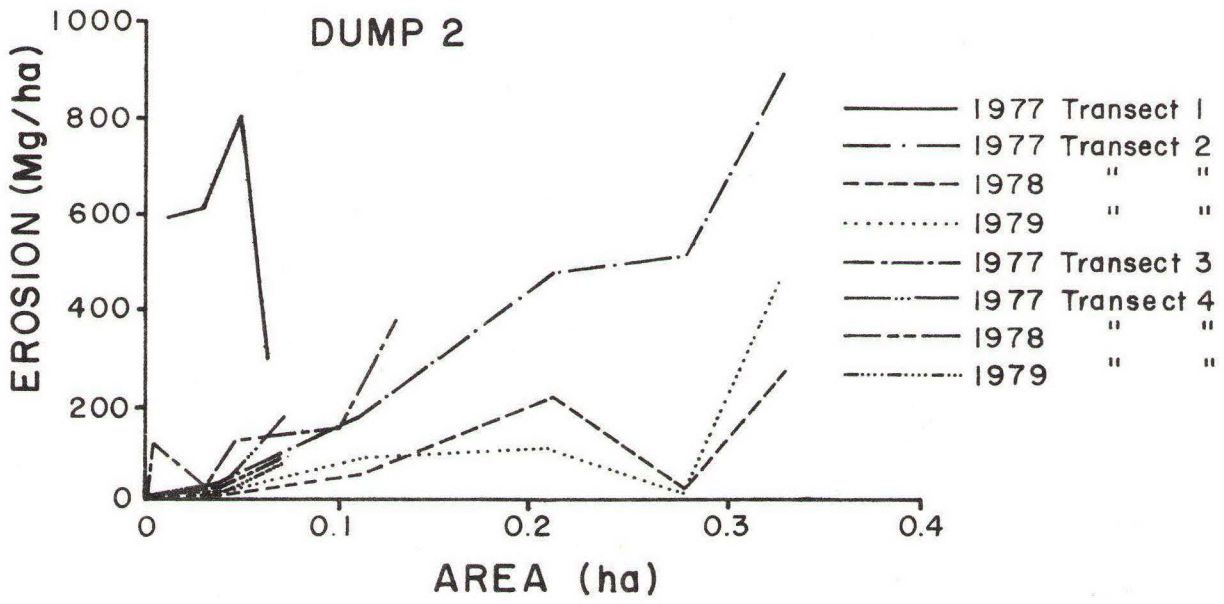


FIGURE 21: Erosion as a function of rill drainage area - Dump 2.

of two factors: either there was a change in the surface of the dump or a change in the runoff which produces erosion. The change in the dump surface is certainly a reasonable conclusion since in the period of a year's time there should have been some consolidation naturally and the regrading would only add to any consolidation. However, when compared to the other dumps it also appears that the erosion causing forces were reduced during the second and third years since there was very little measured erosion increase on any dump.

Discussion and Conclusion

Because of the low number of observations, statistical tests for determining erosional relationships have proved inconclusive. Thus the conclusions below are based mainly on observations.

The major problem in the analysis of erosion from these dumps is the large variation in erosion amounts between dumps and the variation of erosion on all dumps between years.

When the 1977 erosion measurements are compared to the 1978 and 1979 measurements, it is obvious that, in general, the erosion in the first year was much greater than in any of the succeeding years. In fact there appeared to be little or no erosion measured in the next two years. While it is reasonable to expect the greatest amount of erosion in the first year, it is unreasonable to explain the entire trend in this manner. Therefore some other factors must be analyzed and the water available from the snowpack for each year is the most obvious. The relation between the snowpack and erosion is mentioned in more detail in a later section of this report.

There does seem to be some correlation between erosion rates and the snowpack of 1978 and 1979. 1977 was a drought year. While there are no actual snowpack measurements, since the study did not begin until the summer of 1977, the precipitation record of the closest gage (Conda, Idaho) shows 1977 to be 49 percent of the 15 year average. By contrast, the same gage shows 1978 to be 121 percent and 1979 to be 104 percent of the average. This is further supported by snowpack measurements on Dump 2 where the 1979 maximum average snow water equivalent was 78 percent that of 1978. Thus the 1978 and 1979 snowpacks were similar while the 1977 snowpack was much lower.

The large erosion following the small snowpack may be explained if the soil were frozen. When a shallow snowpack covers the ground surface there is very little insulating effect from the snow resulting in frozen ground. During the years of thicker snowpack there is sufficient insulation so that the ground does

not freeze. This was observed in both the 1978 and 1979 winters while making the snow measurements. It has been shown by Lee and Molnau (1979) that runoff on frozen ground usually produces greater erosion than runoff on unfrozen ground. Therefore it is conceivable that in 1977, even though there was a shallow snowpack, there could be large amounts of erosion.

In addition, the different snowpacks could undergo completely different patterns of snowmelt. For example, a shallow snowpack could melt completely in a relatively short time resulting in a high percentage of the water going into surface runoff and consequently causing erosion. By contrast the deeper snowpack, when exposed to the same climatic conditions, would last longer due simply to the greater heat required to make it disappear and the greater water storage in the snowpack. This would result in the melt water being held at the snow-ground interface (at least until channels were formed under the snow) and allowed to infiltrate, thus reducing the amount of surface runoff experienced. Support of this hypothesis is shown by the extensive slumping experienced in the spring of 1978.

This theory however, does not explain why in most cases no erosion was measured in 1978 and 1979 since there should have been some surface runoff regardless of increased infiltration. A possible explanation for this is that the rill channels became armored in 1977. What is suggested here is that in unsorted material (i.e. the dumps) the rill channel formation may be analogous to an armored streambed. At a given flow, all small material up to the maximum size which could be moved by the available tractive force, would be flushed out. This would leave a layer of large material in the rill bottom. This layer of material would not be moved unless there were a velocity greater than that which deposited it. Therefore, if the rill were formed during a year with high surface runoff or under conditions conducive to high amounts of erosion, there would be little additional erosion in following years of less surface runoff.

There appears to be no correlation between erosion and percent slope since the steepest slope resulted in the lowest erosion on Dump 6. The dump with the greatest erosion, Dump 7, does have steep slopes but since other dumps (Dump 6 and Dump 8, Transect 1) have about the same slope, there appear to be other factors which have greater influence.

The relationship between erosion and slope length also shows little correlation between dumps. Again Dump 6, which had the lowest erosion, had long slope lengths especially after the first measurements, when slumping reduced the meas-

urable slopes on Dumps 7 and 8. However, when analyzed on a dump by dump basis, there are trends in the data. For example, on Dump 7 there is an increase in erosion as slope length increases over the whole length of the dump except at about mid-slope. This same relationship holds for Dump 2 (1977) if Transect 1 is ignored for reasons stated earlier. Dump 6, Transect 2, shows a similar trend. However, in this case, there is little erosion on the upper part of the slope, while the erosion gradually increases over most of the remaining slope until, near the bottom of slope, when the erosion increases rapidly. In contrast, Transect 1 on the same dump shows no pattern of erosion increase with slope length. The general conclusion is that erosion does increase with slope length but, that for the highly variable spoils material of a dump, it is difficult to establish any clearcut relationship.

The erosion versus drainage area analysis reveals only that the pattern of rill formation significantly affects the erosion per unit area. This is shown in the Dump 7 analysis, the only dump where the two types of rill patterns were observed. Although this is a rather limited data base, the conclusion is that more total erosion will result where parallel rills form. The objective in dump design and construction should therefore be to avoid dump topography that may result in parallel rills.

SNOW DRIFT RESULTS

The objective of the drift portion of the study was to relate the size of snow drifts to the topography of the disturbed area. The purpose is to give the manager a tool to aid in the determination of the quantity of snow accumulation trapped in topographic catchments both occurring naturally and manmade. Examples of where this information would be useful is in the design of diversion drainage channels on dump tops or in locating dumps in relation to the natural topography to avoid drifting snow from accumulating on the dump face creating a potential erosion hazard.

Introduction

The most successful work done in this subject area has been by Tabler (1975a), in which he constructed a multiple linear regression model to predict an equilibrium drift slope as a function of terrain slopes of the catchment area. The equilibrium slope is defined as that snow slope which will exist when a trap has reached saturation. The trap can only reach saturation under theoretical conditions, namely an infinite snow supply. Since this never occurs

in nature, the equilibrium slope is a maximum slope which will be approached under field conditions. The usefulness of such a parameter is based on a drift growth pattern where the ultimate depth is approached more quickly than the ultimate length. This results in a drift with a smooth slope which breaks off sharply in a cornice when the catchment area is far below saturation. The drift approaches the equilibrium drift slope in its initial growth stages and as accumulation occurs the drift grows along near the equilibrium slope but never quite reaching it. In this way all drift measurements up to the maximum accumulation in the drift should approach the slope predicted by the model.

The model is:

$$Y = 0.25X_1 + 0.55X_2 + 0.15\ X_3 + 0.05X_4$$

if X_2, X_3, $X_4 < 0.20$ then X_2, X_3, $X_4 = -0.20$

where Y = snow slope over main portion of the drift

X_1 = average terrain slope over a distance of 45 m upwind of the catchment

X_2, X_3, X_4 = ground slopes over distances 0-15 m, 15-30 m, and 30-45 m downwind of the trap lip.

The variables and definitions of the model are illustrated in Figure 22 for an idealized example. Slopes upward in the direction of the wind are taken as positive and slopes downward are negative. For the sites used in this report, the average ground slope of X_1 was assumed equal to the actual slope between the catchment and 45 m upwind since the slopes were nearly uniform in all cases.

It should be emphasized here that the drift profiles that are calculated are equilibrium profiles and represent only the slope of the drift after long periods of time. The actual shape of the drift profile was not predicted. Comparisons should be made between the predicted and observed slopes only.

Results

A total of 12 profiles were measured at two sites on natural ground and on four dumps. Two sites, Grays Range and Conda Mine, were measured in the 1976-77 winter but produced very little data due to the drought conditions. The Conda mine site was then abandoned but the Grays Range Site was measured during the following two winters. The remainder of the sites were measured from one to four times during the 1977-78 and 1978-79 winters depending on location and weather conditions. The measured and computed drift profiles are

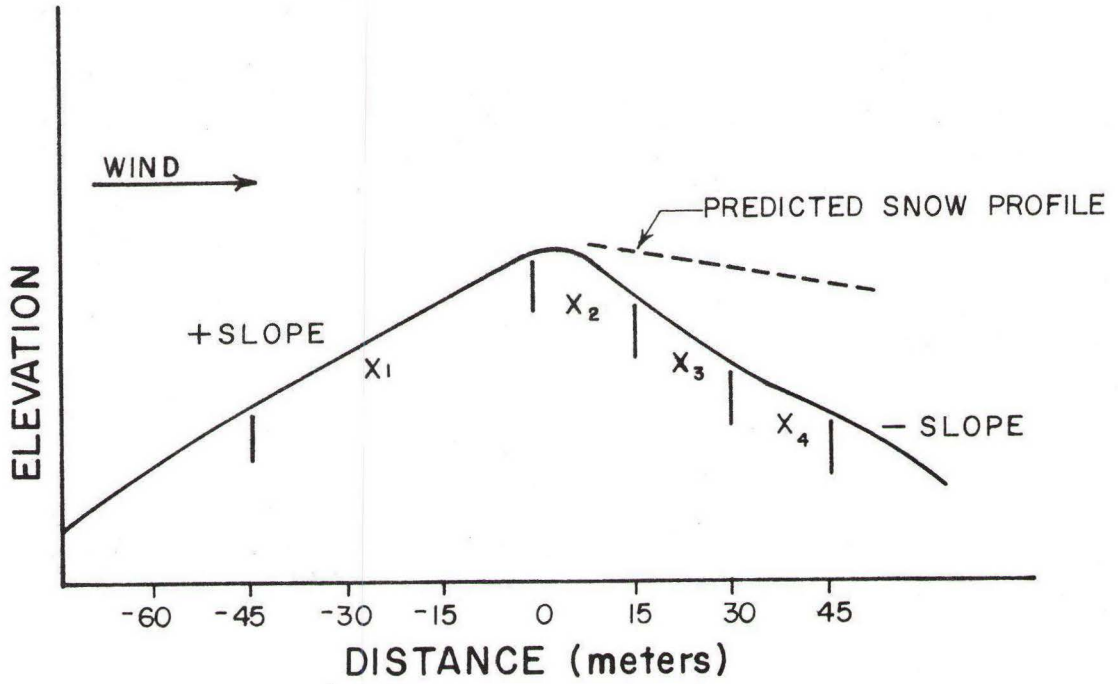
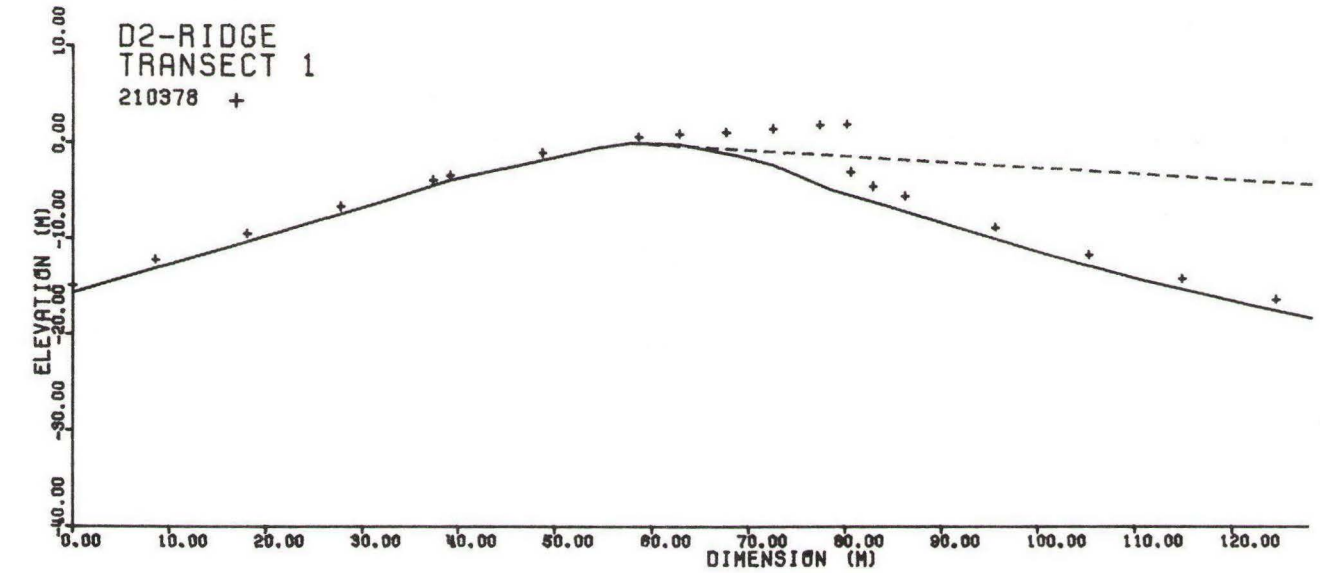


FIGURE 22: Definition sketch of snow drift model variables.

shown in Figures 23 through 32. The site terrain data are summarized in Table 2 in the form of Tabler's parameters X_1, X_2, X_3 and X_4 since these are values that can easily be compared from site to site and can be used to compare these data to other locations. Only the maximum profiles for each year at each site are shown in the figures.

The sites can be placed in three groups based on the leeward ground slope of each site. The off dump sites, the three profiles of Dump 2 Ridge (D2R-1, D2R-2, D2R-3) and the one profile on the Grays Range Site (G-2), form a group with negative leeward ground slopes. All the sites in this group had a negative predicted snow slope ranging from -0.05 to -0.11 as shown in Table 2. The measured slope on the three profiles on the Dump 2 Ridge (Figures 23, 24 and 25) had positive snow slopes for peak drift accumulation (3/78, 3/79) ranging from 0.02 to 0.10 but generally in close agreement from year to year at the individual sites. At all three sites, the measured drift profile was greater



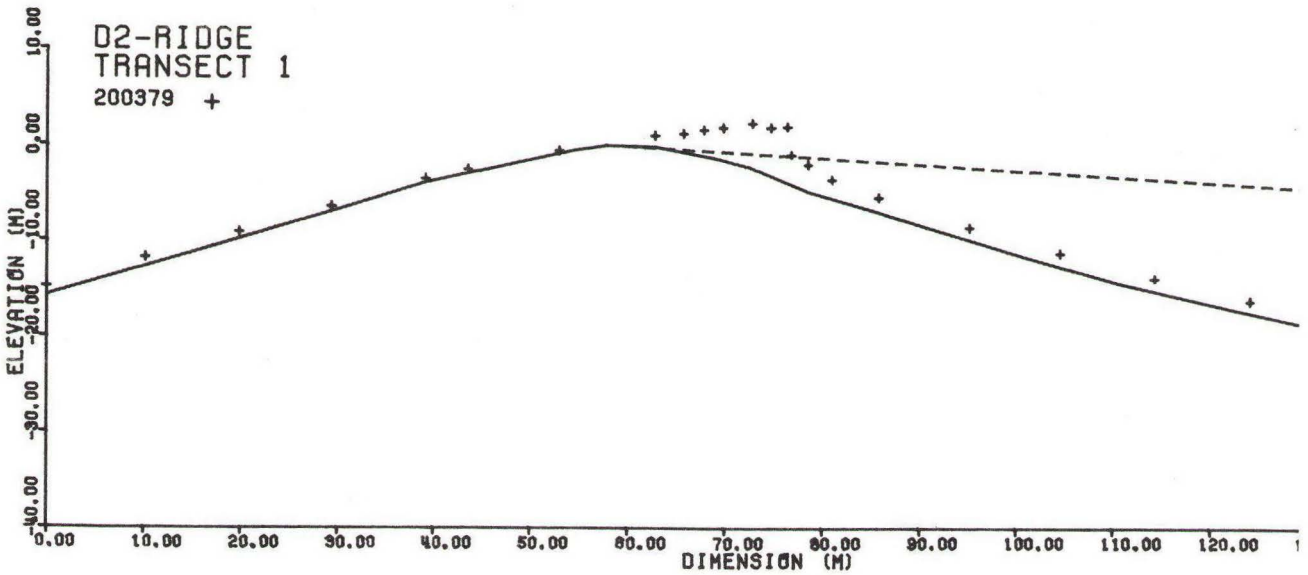
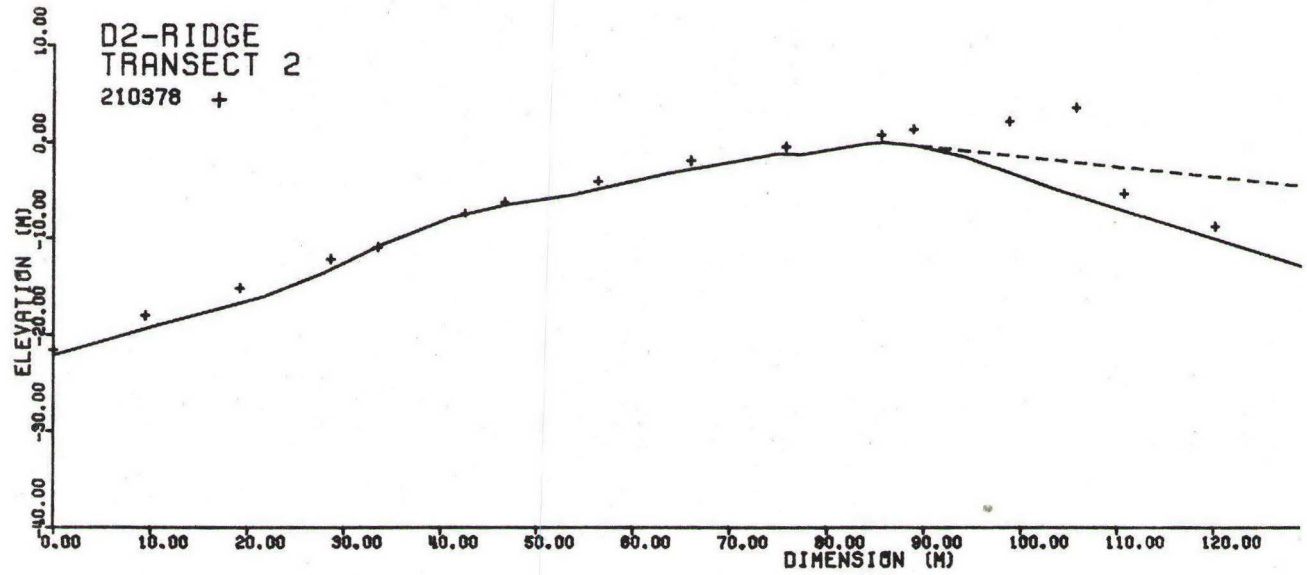


FIGURE 23: Snow profiles. Dump 2 Ridge, Transect 1. 1978, 1979.



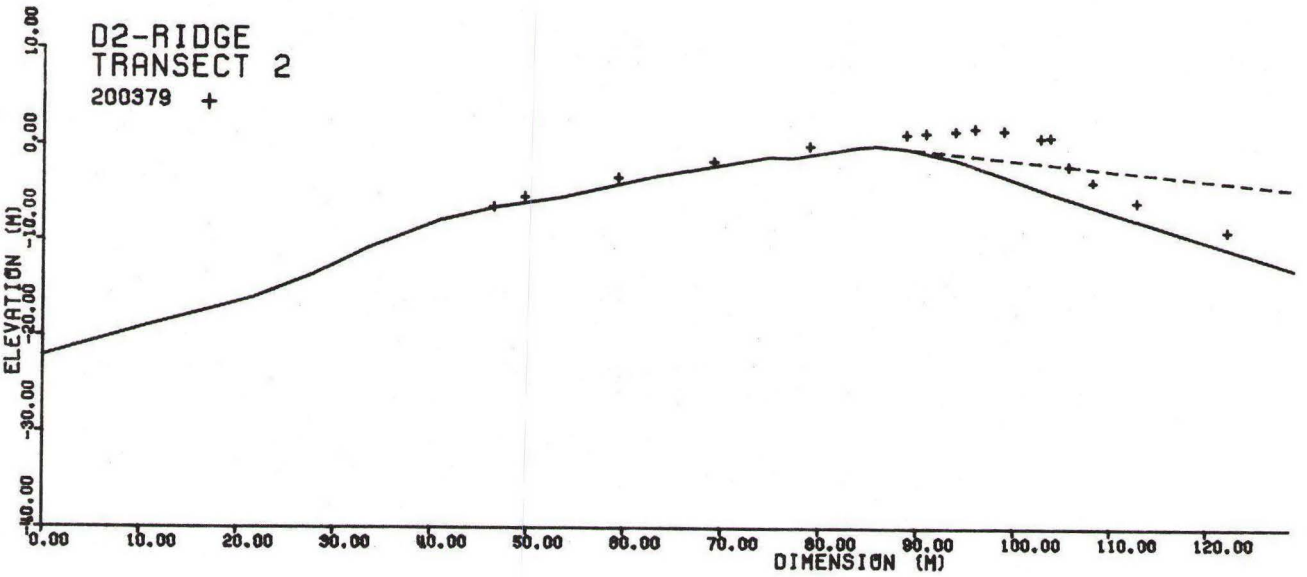
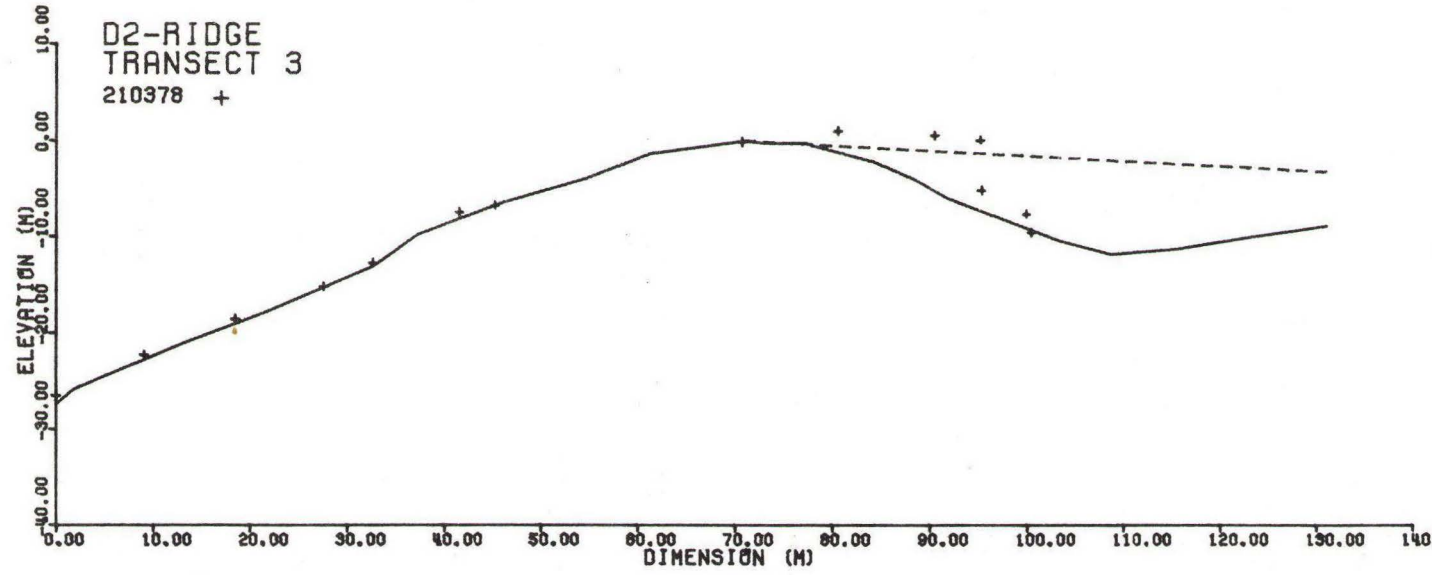


FIGURE 24: Snow profiles. Dump 2 Ridge, Transect 2. 1978, 1979.



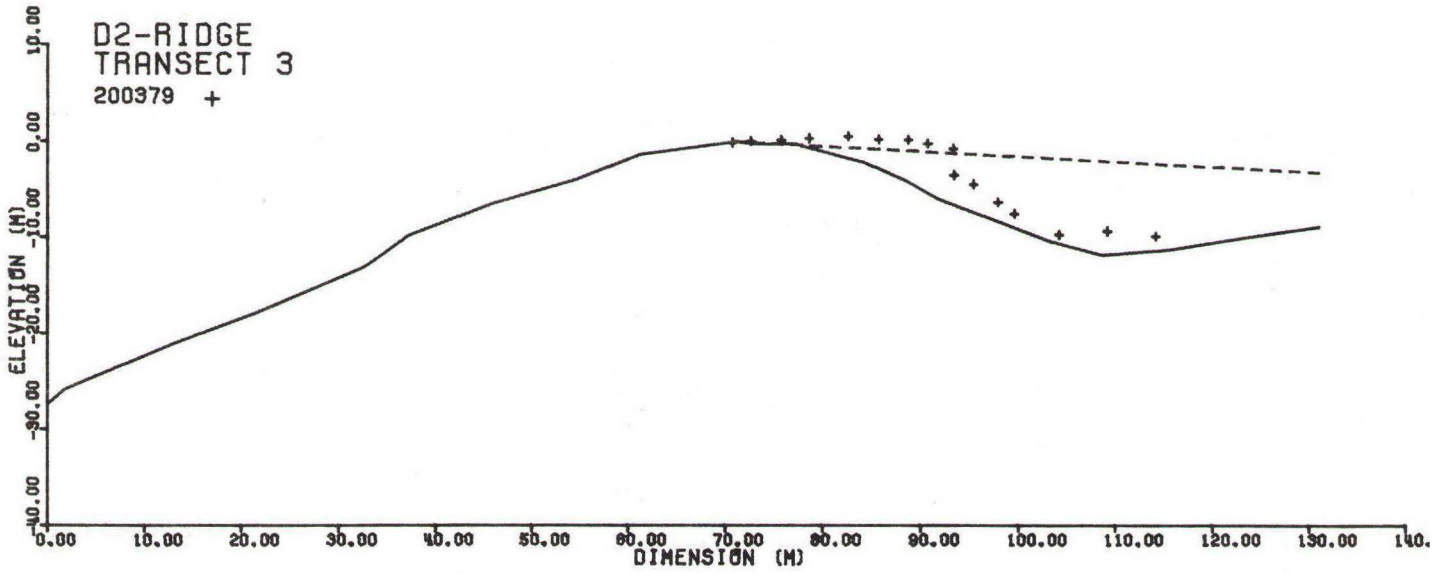


FIGURE 25: Snow profiles. Dump 2 Ridge, Transect 3. 1978, 1979

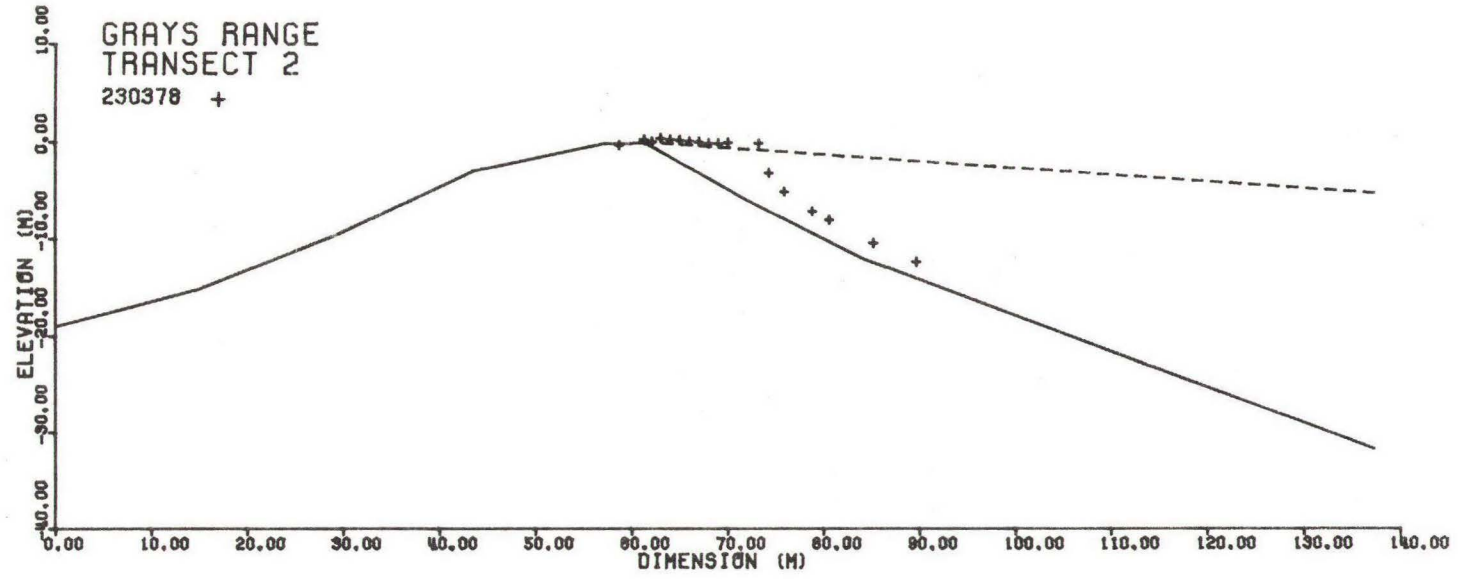
than the predicted drift profile. The Grays Range Site (Figure 26, 27) had very good agreement with the predicted profile and drift slopes in both years.

The second group of sites is based on nearly flat leeward ground slopes. The three profiles from Dump 5 (D5-1, D5-2, D5-3), the one profile from Dump 7 (D7-2) and the two profiles from Dump 8 (D8-1, D8-2) fit in this category (Figures 28, 29, 30). The predicted snow slopes in all cases were positive and ranged from 0.04 to 0.12. The actual profiles were in excess of the predicted in all cases except the Dump 7 Site. As can be seen from Figures 28 through 30, the actual profiles seem more rounded at their points of maximum depth than sites in the first group but the predicted profile appears to match the measured profiles much closer than did the sites in the first group. The Dump 7 Site (Figure 23) never had a straight slope profile as predicted but was always concave upwards. However, from inspection of the figure, there was close agreement with Tabler's model. The most significant point about this site is that, of all the locations measured, only this site never exceeded the profile predicted by the model. There does not appear to be a logical reason for this. The profiles of Dumps 7 and 8 had a significant rise in the leeward slopes within 45 m of the trap lip but the Dump 8 profiles were underpredicted just like the others.

The third group consists of the two sites on Dump 6 (D6-1, D6-2) in which the leeward ground slopes are positive (Figures 31 and 32). The predicted snow slopes of 0.29 and 0.30 were very close to actual snow slopes which ranged from 0.21 to 0.28 on D6-1 and 0.25 to 0.34 on D6-2. An inspection of the profiles shows very close agreement with the predicted snow slopes on D6-1 and slightly higher accumulations than predicted at D6-2.

Discussion and Conclusions

In nearly all cases the profiles measured in this study were greater than those predicted by the Tabler model in its present form. This was foreseen by Tabler since the model was developed from data in gentle to moderately rolling terrain. He anticipated that the greater turbulance of more mountainous terrain would cause steeper snow drift slopes. Modification of the model to fit the phosphate mining region is beyond the time limitations of this study. For now, the data provided can be useful in design or management applications. The simplest application is to compute the terrain slopes X_1, X_2, X_3 and X_4 for the location in question, and to compare those values to those in Table 2 to find the best match. By then comparing the matched site's actual slope and predicted slope to the predicted slope of the site in question, an approximate prediction can be obtained.



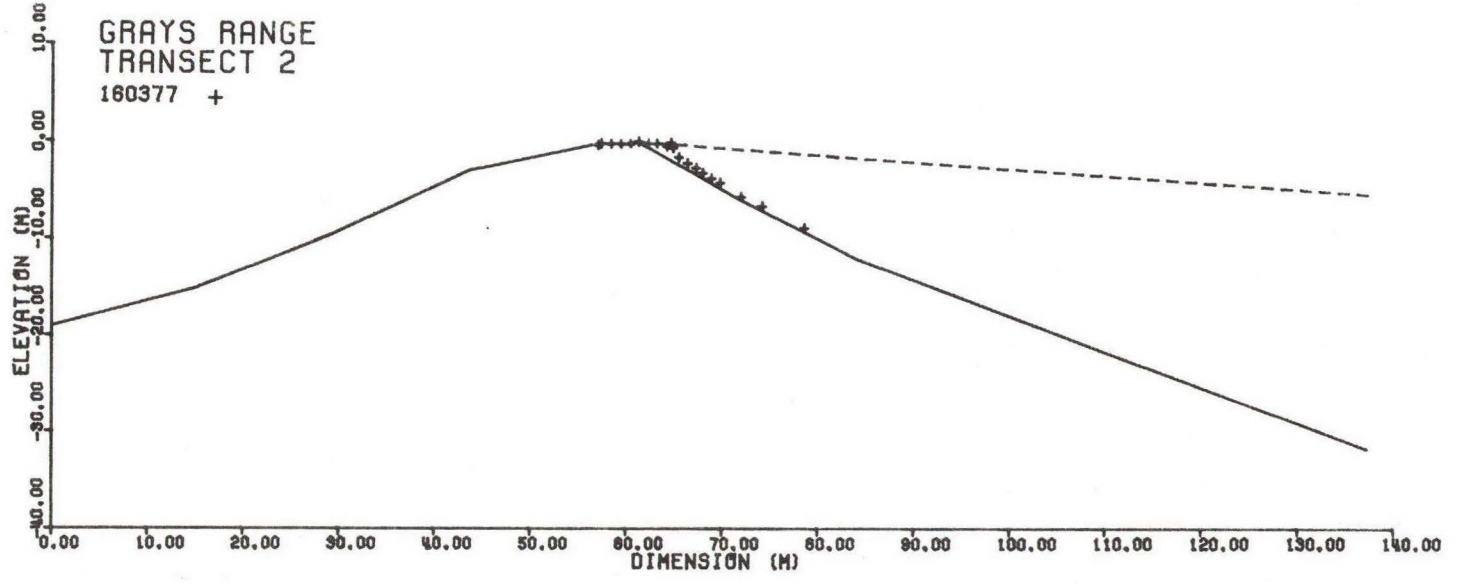


FIGURE 26: Snow profiles. Gray's Range, Transect 2. 1977, 1978.

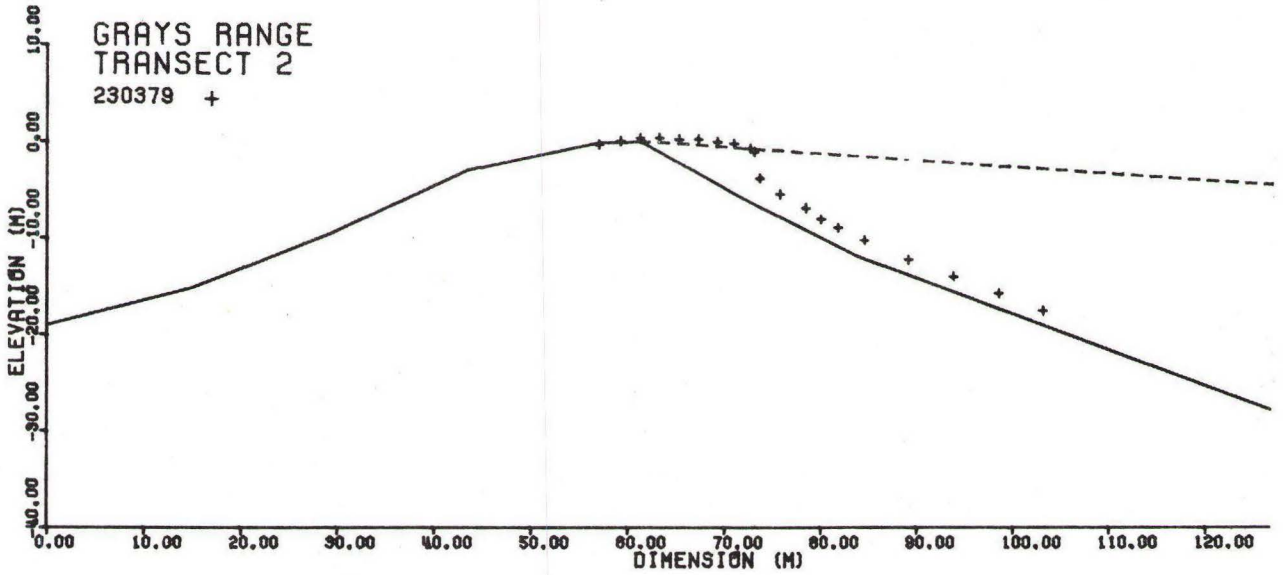


FIGURE 27: Snow profile. Gray's Range, Transect 2. 1979.

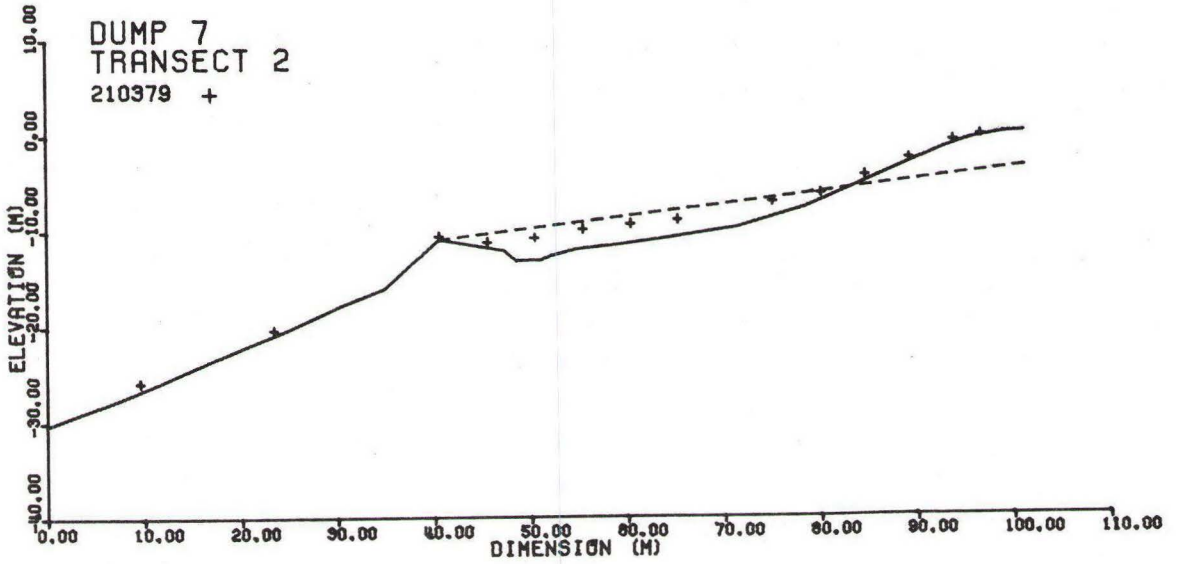


FIGURE 28: Snow profile. Dump 7, Transect 2. 1979.

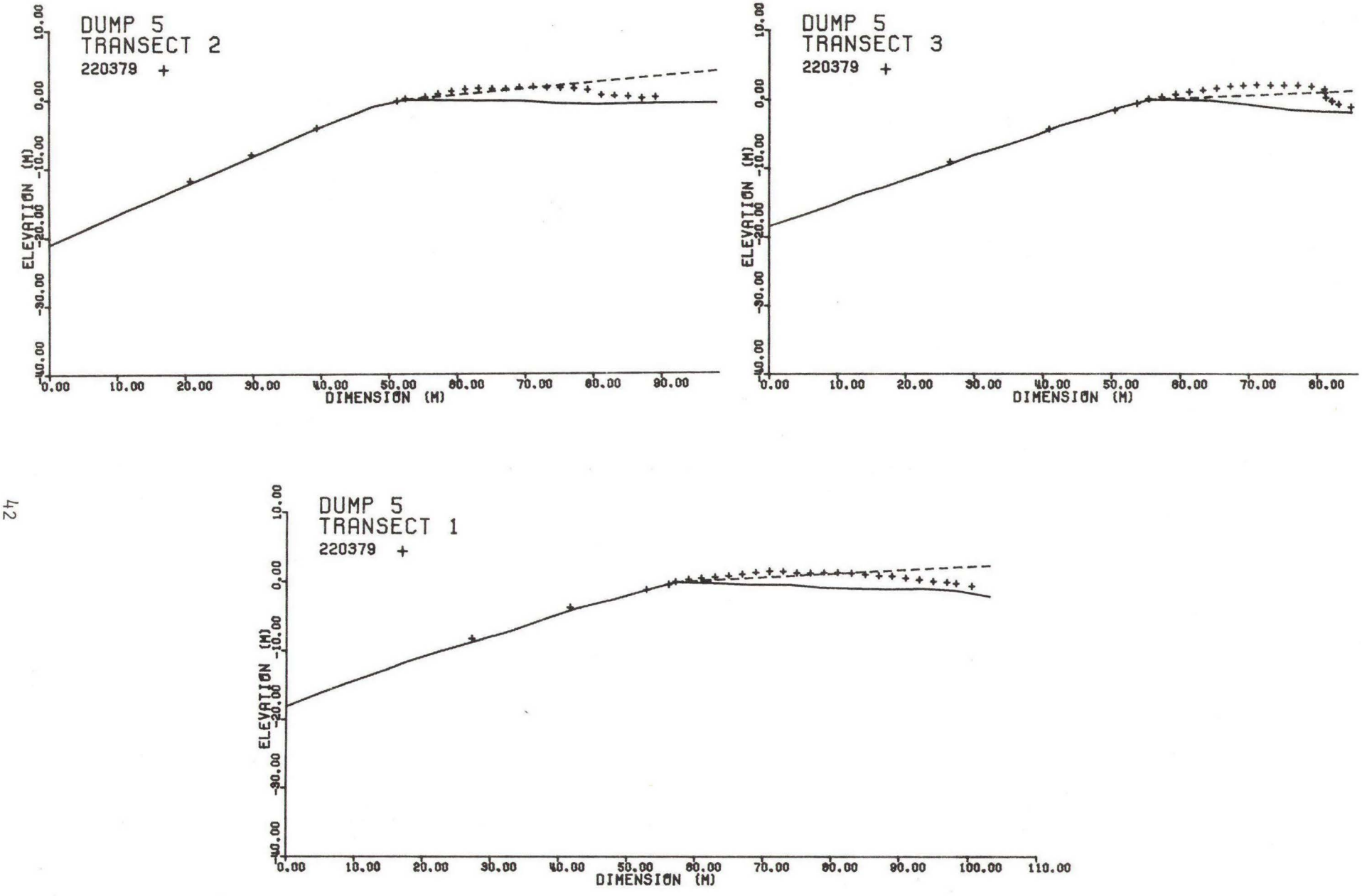
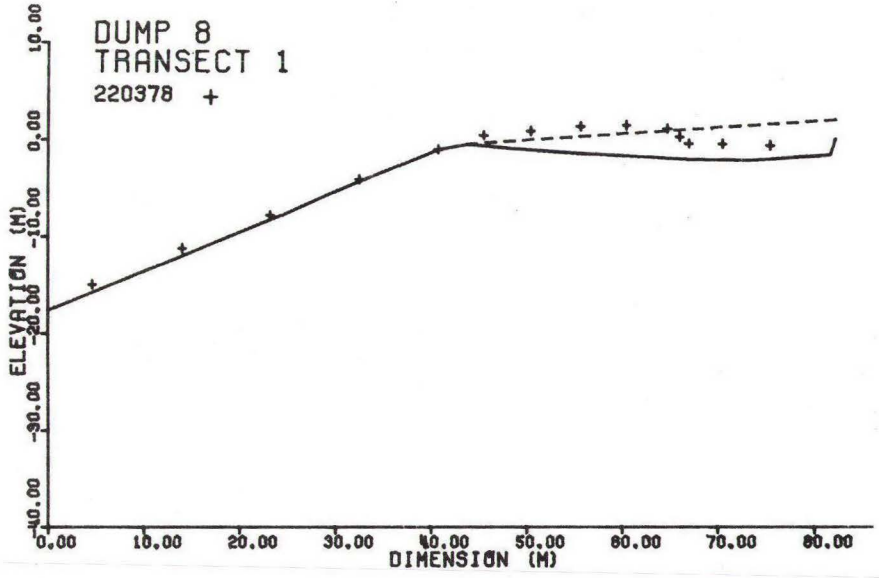
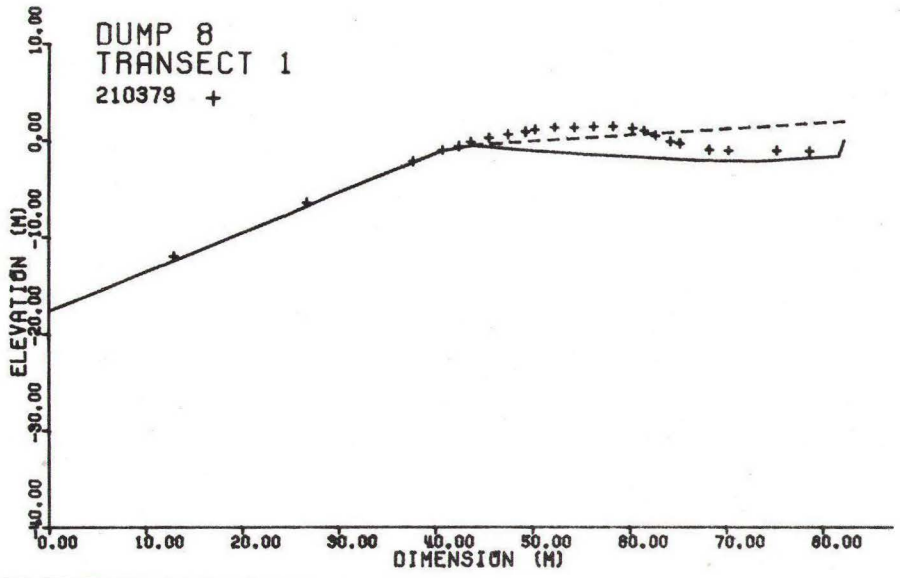


FIGURE 29: Snow profile, Dump 5, Transects 1, 2 and 3. 1979.





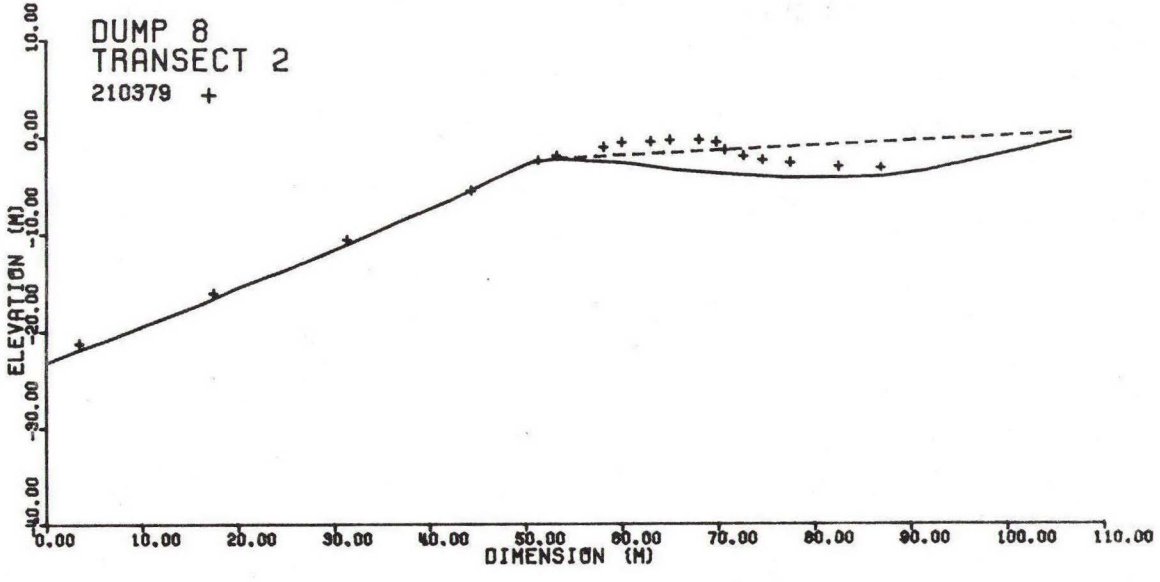
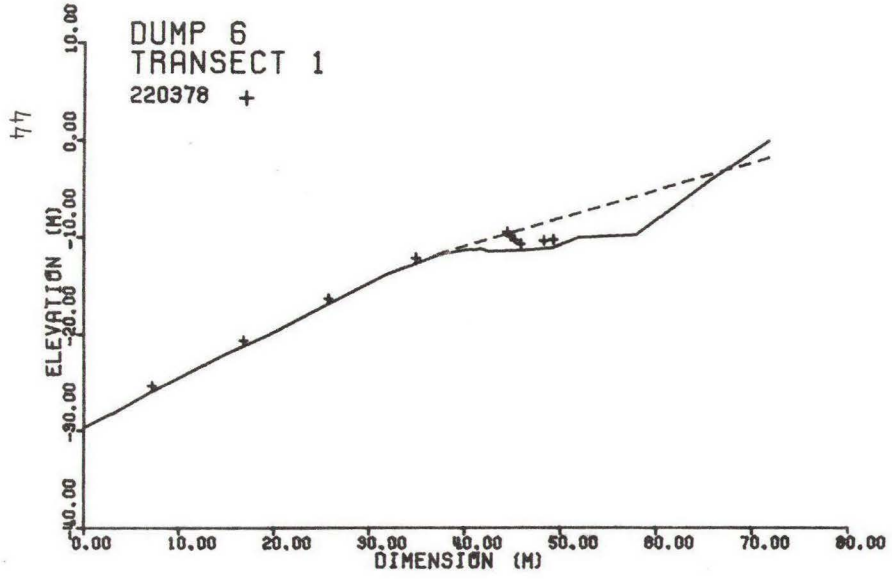


FIGURE 30: Snow profiles. Dump 8, Transects 1 and 2. 1978, 1979.



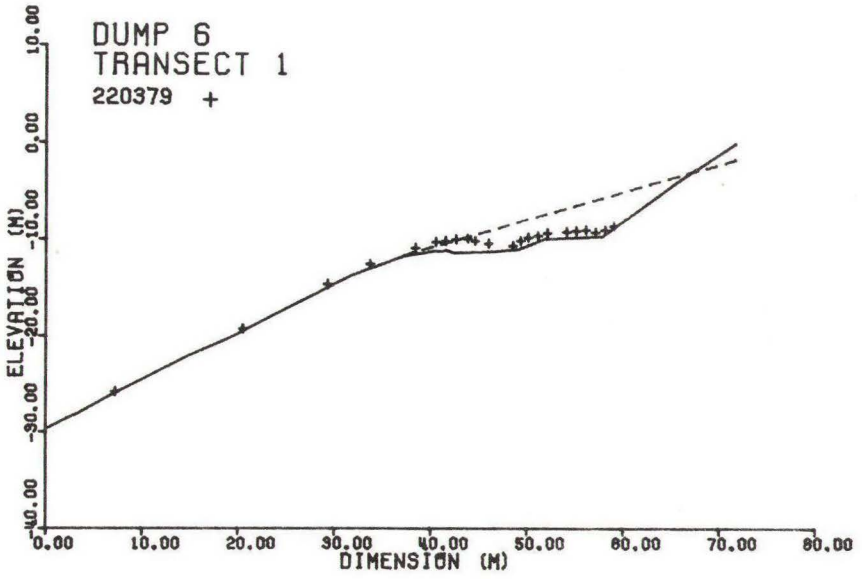
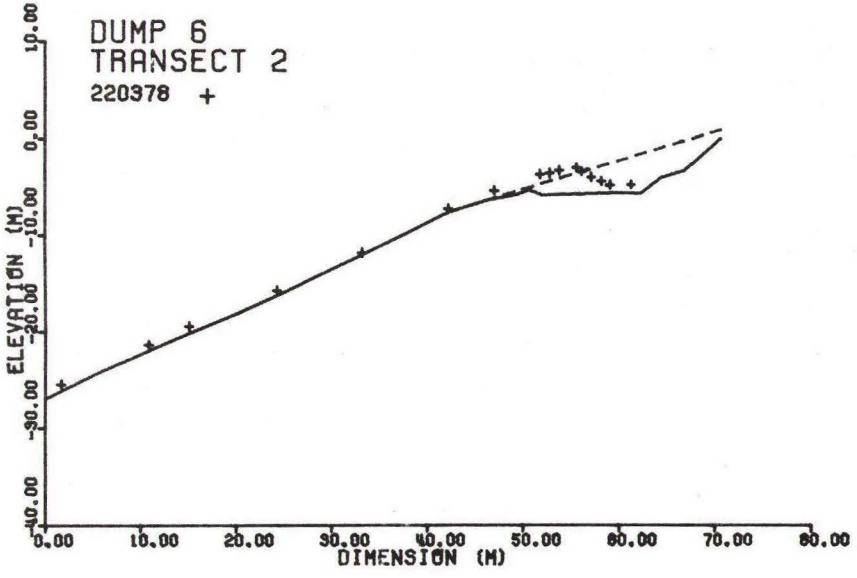


FIGURE 31: Snow profiles. Dump 6, Transect 1. 1978, 1979.



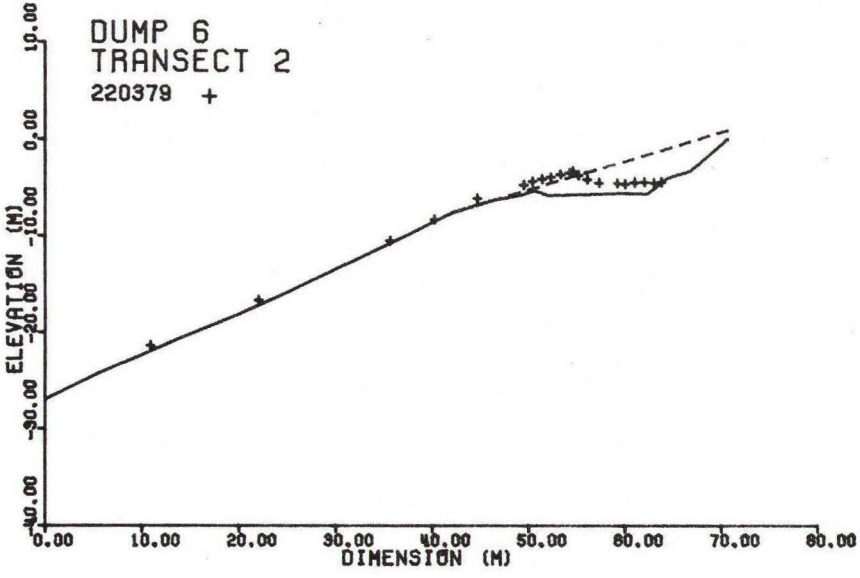


FIGURE 32: Snow profiles. Dump 6, Transect 2. 1978, 1979.

TABLE 2: Drift model parameter comparison.

Site	Tabler's Parameters					Measured Snowslopes				Densities** gm/cm^3	
	X_1	X_2*	X_3*	X_4*	Y	1/78	3/78	1/79	3/79	1/78	3/79
D2R-1	0.26	-0.16	-0.35	-0.30	-0.06	0.07	0.05	-0.02	0.06	.44-.45	.41-.47
D2R-2	0.18	-0.26	-0.32	-0.31	-0.11	0.11	0.10	-0.08	0.05	.41-.47	.39-.42
D2R-3	0.35	-0.19	-0.44	-0.11	-0.05	0.03	0.04	0.03	0.02	---	.38-.43
G-2	0.32	-0.54	-0.44	-0.37	-0.07	--	-0.04	--	-0.05	.39-.42	---
D5-1	0.30	-0.02	-0.04	-0.06	0.05	--	--	--	0.09	---	---
D5-2	0.40	-0.01	-0.03	0.01	0.09	--	--	--	0.11	---	.34-.46
D5-3	0.33	-0.05	-0.07	-0.04	0.04	--	--	--	0.13	---	---
D7-2	0.47	-0.06	0.13	0.34	0.12	0.15	--	--	0.12	---	.42-.47
D8-1	0.39	-0.07	-0.03	0.24	0.07	0.05	0.09	--	0.11	.46	.34-.40
D8-2	0.40	-0.09	-0.04	0.14	0.05	--	--	--	0.11	---	.36-.40
D6-1	0.48	0.12	0.47	0.66	0.29	0.25	0.28	--	0.21	---	.38-.46
D6-2	0.46	0.13	0.46	0.85	0.30	0.25	0.34	--	0.28	---	.37-.47

* Note that for purposes of calculation in Tabler's model those values less than -0.20 are set equal to -0.20.

** Densities are at selected points on the drift.

The amount of water in the drift can be estimated once the profile is known by using an average snow density. The range of densities measured on the drifts at the study sites are shown in Table 2. The densities were not measured across the entire drift profile but only where depths were less than 3 m (the maximum depth capacity of the equipment used). The snow density of the profile at depths greater than 3 m has been assumed to be in this range and most likely are at the upper limits. As shown in Table 2, the densities for all drifts during the two years of measurements ranged from 0.34 to 0.47 gm/cm^3. A good average value to be used over the whole drift profile would be about 0.45 taking into account that the greater depth profile would have a higher density.

The lateral extent of the drift must be computed at incremented distances across the face of the catchment area. Further investigations into drift formation in the phosphate mining area should pursue the drift profile prediction as a function of topography and should investigate the areal extent of the drift formation. This can probably be most efficiently studied through the use of aerial photographs to determine areas of drift formation quickly and over a large region. This approach would also require field reconnaissance to obtain verification measurements. This technique has been proposed by Radok (1977) and could be used in conjunction with an aerial photography study of erosion in the mining area.

WATER BALANCE COMPONENTS ON DUMP 2

Balance Components

The water balance for Dump 2 was to follow the continuity equation:

Precipitation = Runoff + evaporation + transpiration + deep percolation + change in soil moisture + change in snow storage

When the instrumentation was installed at Dump 2, an agreement was reached with Farmer concerning the collection and disposition of data. He was to be responsible for the soil moisture and groundwater level measurements while this project would collect the snow and meteorological data. All soil moisture data mentioned in this report is given courtesy of E. E. Farmer, Intermountain Forest and Range Experiment Station, Forest Service, Logan, Utah. (Appendix A).

The water balance given here is very rough and is intended only to give an order of magnitude to the various components of the above equation.

The water input to the dump is precipitation which may be in the form of snow or rain. The precipitation and snow water equivalent summary is shown in Figure 33. The effect of relocated snow due to drifting is quite apparent where the cumulative precipitation curve is below the snow water equivalent line. The precipitation values shown are the average of the gages at the top and bottom of the dump while the snow water equivalent values are the mean of the 54 sampling points of the grid on Dump 2.

The soil moisture was measured with a neutron soil moisture meter at each one of the 54 sampling points. The values of soil moisture in the top three meters is given in Table 3 and plotted in Figure 33. If there is no precipitation input, there is no water input and the change in soil moisture is assumed to reflect the water lost to deep percolation and evapotranspiration.

Surface runoff was not measured but runoff did occur on the dump face as evidenced by the existence of rills. The only location where it is possible

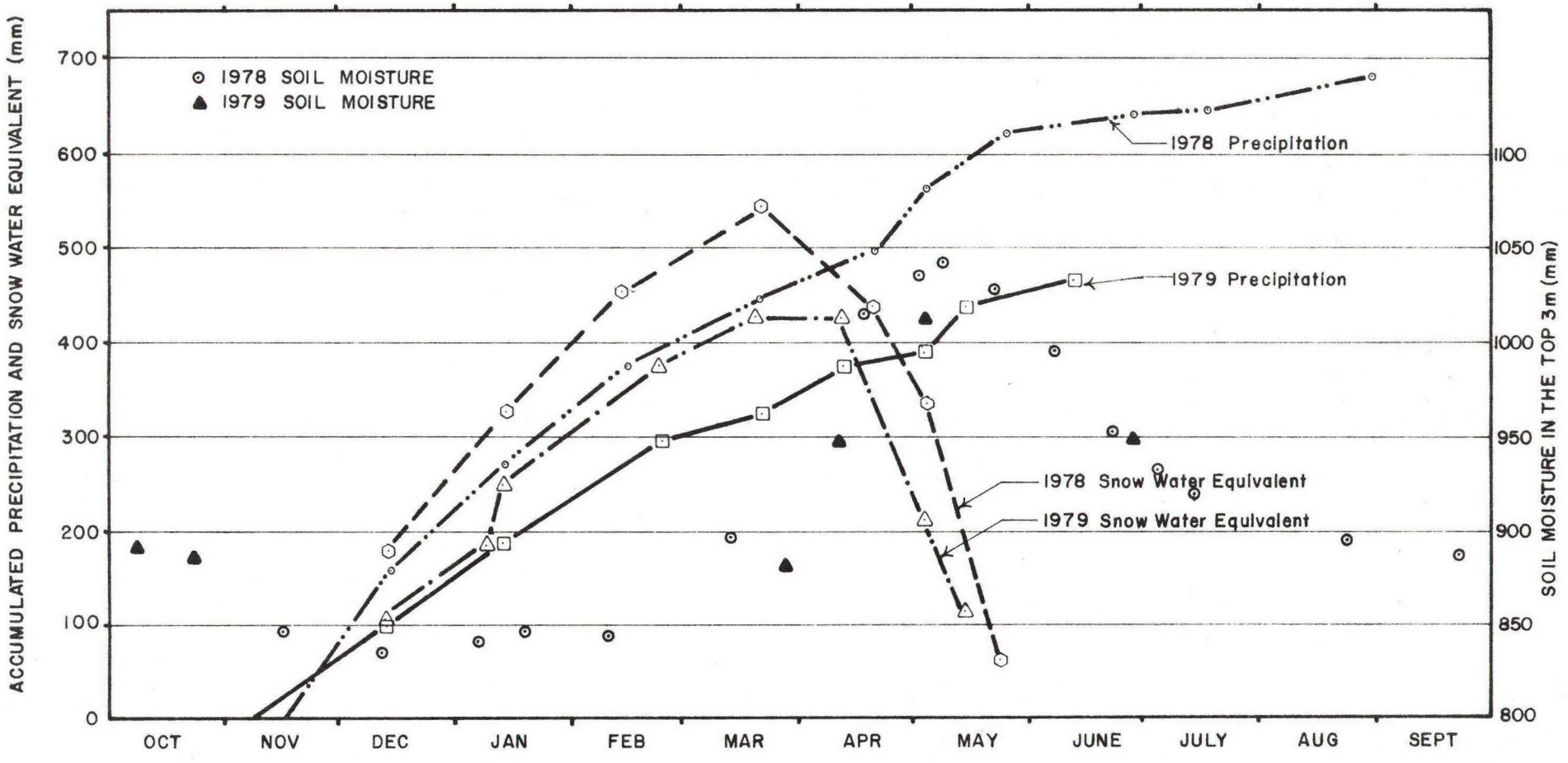


FIGURE 33: Precipitation, Soil Moisture in the Top 3 m, and Average Water Equivalent on Dump 2.

TABLE 3: Precipitation, snow water equivalent and soil moisture on Dump 2. All values in mm.

Date	Precipitation (mm)	Snow Water Equivalent (mm)	Soil Moisture (mm in 3 m profile)
11/17/77	0	0	847*
12/14/77	156	178	838
1/13/78	113	324	342
2/15	105	451	846
3/21	69	543	898
4/20	53	435	1018
5/04	65	331	1038*
5/25	59	63	1027
6/28	15	0	951*
7/18	7	--	924*
8/8	--	--	909
8/30	34	--	898*
9/20	--	--	888
10/06	50	--	889
10/23	--	--	880
11/09	0	--	--
12/13/78	100	109	--
1/09	--	184	--
1/13	87	245	--
2/23	104	374	--
3/21	31	425	--
3/28	--	--	880
4/12	50	422	949*
4/26	--	--	1014
5/03	14	211	--
5/04	0	167	--
5/14	48	115	--
6/12	27	0	--
6/26	--	--	950

Note: Precipitation values are amounts since last date.
Snow water equivalent and soil moisture are readings on the given date.

to measure runoff is at the spillway of the dam at the bottom of the dump. There was no evidence that water flowed over the spillway in 1978-79 although some flow was observed in April and May 1977-78. Both surface and seepage water would accumulate in the pool behind the dam during the day but the water level would always recede due to seepage losses during the night period of low melt. Because of these observations, the runoff is assumed to be nonsignificant or zero.

It is obvious from Figure 33 that drifting played a significant role in moving moisture onto the dump. This fact makes it difficult to say much about the balance. Without a greater knowledge of the evaporation, amount of drifting and deep percolation, any balance attempted now would be seriously in error.

The following general observations about water distribution on Dump 2 can be made at this time:

1. Drifting constitutes a major source of moisture in the winter. In 1978, there was a maximum of 70 mm more snow water equivalent on the dump than cumulative precipitation at maximum accumulation in March. In 1979, the maximum difference was 83 mm.
2. Soil moisture recharge began in late February or early March in 1979. The soil moisture stayed relatively constant during the November-February period of 1977-78 and started increasing in March. There is no reason to expect it not to do the same in 1979. In 1979, the snowmelt lysimeter worked much of the time showing sporadic melt in early March and increased melt in late March and all of April. This is consistent with the soil moisture observations.
3. With much of the snow gone from the dump by May 14, 1979, the soil moisture of April 26 (1014 mm) should be very close to the peak amount for the year indicating that the loss of snow cover greatly increased evaporation from the soil surface so that there was a net loss of soil moisture thereafter.

Sublimation

During the initial stages of the project, a question was raised as to the possible effect of sublimation of the snow on water loss from the snowpack on the dump faces. It has been observed that some areas seem to lose snow without much increase in soil moisture. One possibility is sublimation of the snow.

Sublimation measurements were made during two periods: March 20-22, 1979 during the cold accumulation period and May 3-4, 1979 during the melt period.

The method used was that of Doty and Johnston, 1969. Plexiglass cylinders 150 mm in diameter with a perforated false bottom and a solid bottom to catch meltwater were filled with snow. Three cylinders were placed near the top of the dump and two near the bottom. The cylinders were inserted into the surrounding snow so that the surface of the snow inside and outside of the cylinders were flush. The cylinders were then weighed periodically. The measurements were made approximately between 0900 h to 1800 h and 1800 h to 0900 h for test period lengths of 9 and 15 hours, respectively. The weather conditions during the March sampling period were clear skies, temperatures ranging from a high of 9.9° C to a nighttime low of -6.2° C with very light winds. The conditions in May were also clear skies, temperature range of 11.7 to -0.8° C and light winds. The May samples were taken during a period of rapid snowmelt. The results are shown in Table 4.

TABLE 4: Sublimation data summary, 1979, Dump 2

Date		Temperature (3 hr avg, °C) Max.	Min.	Humidity (%)	Wind (kph)	Sublimation, calculated (mm/day)	Sublimation, observed (mm/day)
3/20/79	Day	1.6	- 0.7	53	12.7	-2.27	-0.59
	Night	- 2.7	- 4.7	60	12.4	-1.30	0.22
3/21	Day	8.9	2.3	37	6.2	-0.99	-0.68
	Night	- 2.4	- 4.3	73	5.6	-0.41	0.13
3/22	Day	9.9	2.8	37	7.6	-1.22	-0.59
		day mean = -0.62 mm/day			night mean = 0.18 mm/day		
5/03	Day	10.9	9.5	37	9.2	-0.93	-0.98
	Night	7.2	4.7	44	10.8	-1.18	-0.51
5/04	Day	11.7	11.1	38	19.8	-1.23	-1.08
		day mean = -1.03 mm/day					

The value of the relative humidity for the March period is approximate only since the humidity transducer malfunctioned for a ten day period. The values shown here were obtained by assuming that the mixing ratio of the air is a conservative

quantity during this period and comparing the humidity values so obtained to similar periods with good humidity readings.

The equation used for computing sublimation is taken from Williams (1959). Computations were made in three hour increments. The equation is:

$$Q = 0.0607V\ (e_a - e_s)$$

where

Q = snow sublimation in mm/day

V = wind speed in kph

e_a = air vapor pressure in mb

e_s = snow surface vapor pressure in mb

The value of e_s was taken as 6.11 mb when the air temperature was above freezing. The snow surface temperature, T_s, was assumed equal to the air temperature anytime the air temperature, T_a, was below freezing. This assumption leads to the problem of not being able to compute any condensation when T_a is below freezing. During periods when back radiation is high (clear sky, especially at night) T_s can be considerably below T_a resulting in condensation as observed during the nights of March 20 and 21. Condensation would occur during a period of high relative humidity (above about 30 percent) with T_s a few degrees below T_a.

As seen in Table 4, the calculated and observed sublimation amounts follow the same pattern (up during the day and down at night), but without snow surface temperatures, it is impossible to obtain a closer match of calculated and observed values. During the melt period, however, the calculated and observed values are very close during the day but further apart at night. Once again, the explanation probably is that T_s drops below T_a at night.

The purpose of these calculations and measurements was to determine the size of the sublimation component of snowmelt. As seen here, this is not a large value. During these same periods, the lysimeter measured no melt in the March period and 61 mm during the May period. The conclusion is that sublimation, while present, was not significant during the period of measurement and that the equation presented can be used to compute sublimation during the melt period.

Snow Distribution on Dump 2

The many points at which snow depth and water equivalent were taken allows several comments to be made about the distribution of snow over the dump face. The dump topography is one factor over which the mining companies can exercise some control, although this control is itself governed by the overall dump site. Observation of the general pattern of accumulation and melt suggests that

these patterns were similar during each of the study years. This being the case, it should be possible to determine, at least in a statistical sense, the effect of dump topography on the snow pattern. Because of the interplay between accumulation and melt, it is not possible to apply the same snow drift model as that used on the ridge crests, which predicts the equilibrium profile slope, a situation which was not even approximated on the face of Dump 2.

The topographic variables measured at each sample point on the intensive study area were aspect, slope, distance from and elevation difference to the ridge line in the direction of the prevailing wind. A correlation was performed between the snow variables and the topographic variables for each month for the 1978 and 1979 seasons. Significant results are shown in Table 5.

The distance to the ridge and the slope at the sample point were not significant but aspect and elevation difference were significant. It does not appear to make any difference whether depth or water equivalent is used

TABLE 5: Correlation coefficients between snow and topographical variables (1978 data with 1979 data in ( )).

Month	Elevation Difference		Aspect	
	Depth	Water Equivalent	Depth	Water Equivalent
December	.499	.380	.342	.364
January	.474	.475	.287	.352
	(.462)	(.423)		(.313)
February	.471	.449		.276
	(.492)	(.404)		(.286)
March	.455	.414		.320
	(.457)	(.472)		(.265)
April	.474	.476	.276	.297
	(.408)	(.379)		(.278)

5 percent level 0.264. 53 degrees of freedom.
1 percent level 0.342.
0.1 percent level 0.429
Non significant values are not shown.

except for the December, 1977, reading for elevation difference. No reason is apparent for this one month deviation.

There appears to be no time trend to the correlation coefficients between elevation difference and the snow variables but a weak trend is discernable in the water equivalent and aspect relationship. There also does not appear to be any difference in the correlation coefficients between the 1978 and 1979 seasons.

In Figures 34 and 35, the contours of maximum water equivalent for each year are shown. These show very clearly that the pattern of accumulation is the same for both years even though there is a large difference in precipitation. When the difference in water equivalent between any two sample dates is considered (Figures 36 and 37) the melt period in May of both years show similar patterns. These figures confirm the observation that in normal years, it is the topography that controls the patterns of melt while it is the weather that controls the rate of melt.

Figures 5, 34 and 35 show a break in the contour lines and accumulation and melt patterns which separates the dump into an eastern and western portion at an aspect of 200^{o} . This suggests the possibility of considering the dump in two separate portions. A correlation matrix was again constructed. This time the division is between points with an aspect of less than 200^{o} and those with an aspect greater than 200^{o}. Both years are grouped in this analysis. The results are shown in Table 6.

In this analysis, none of the three topographic variables are significant for the East side of the dump except for December. The correlation coefficient for distance is negative and that for elevation difference is positive which means that the further from the ridge, the less snow will be found but the closer to the bottom of the dump, the more snow is accumulated. This is true only for the early winter and not for the remainder of the year. This probably is due to the fact that the early snow is wind distributed more than later snow. Also, the West aspect has less snow on it later in the season because much more melt will occur on the west facing slope (aspect less than 200^{o}). This melt makes it much more difficult to correlate the accumulated snow with locational variables because the melt relationship overrides the accumulation-topography relation.

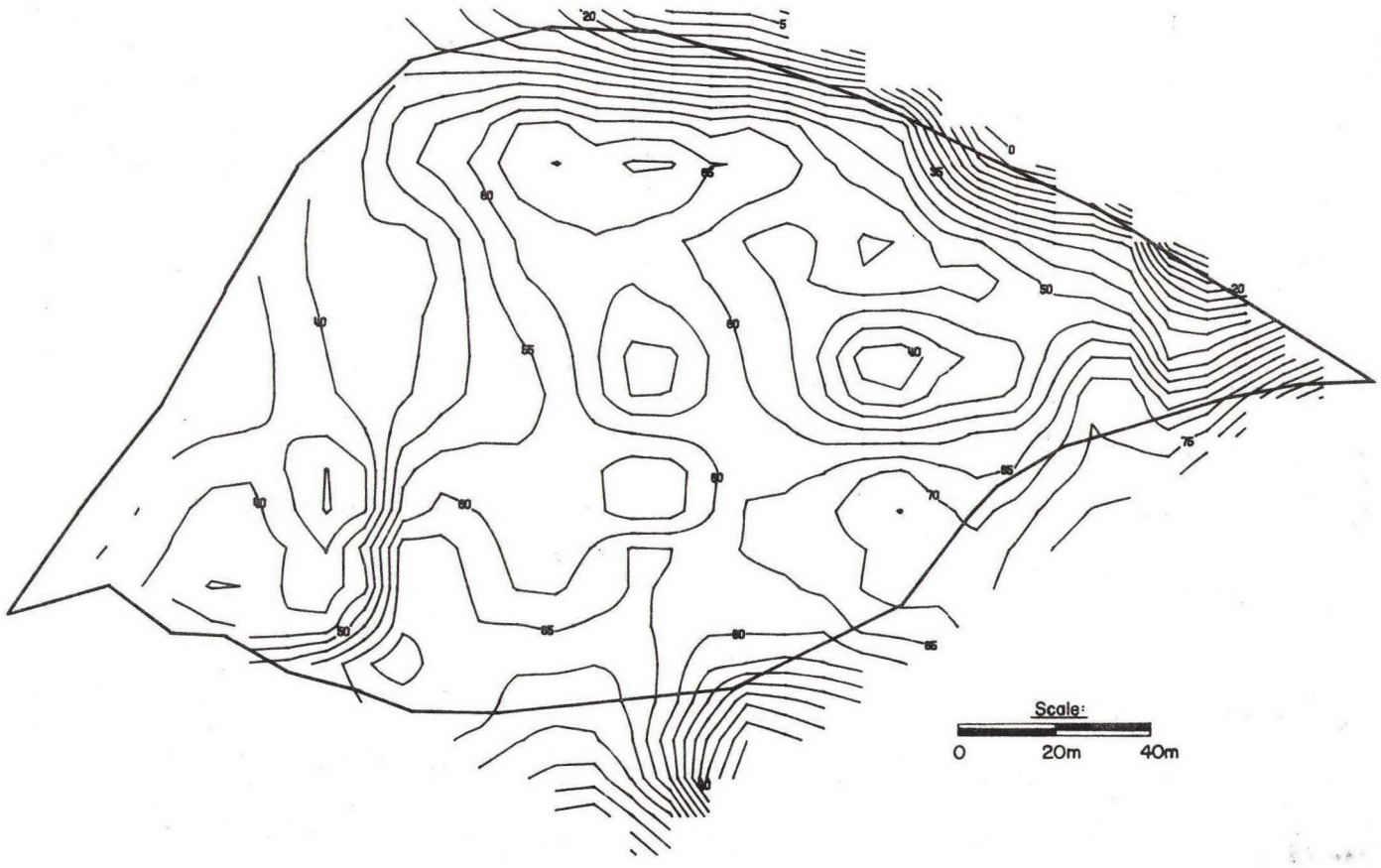


FIGURE 34: Maximum water equivalent of the 1978 season. March 21.

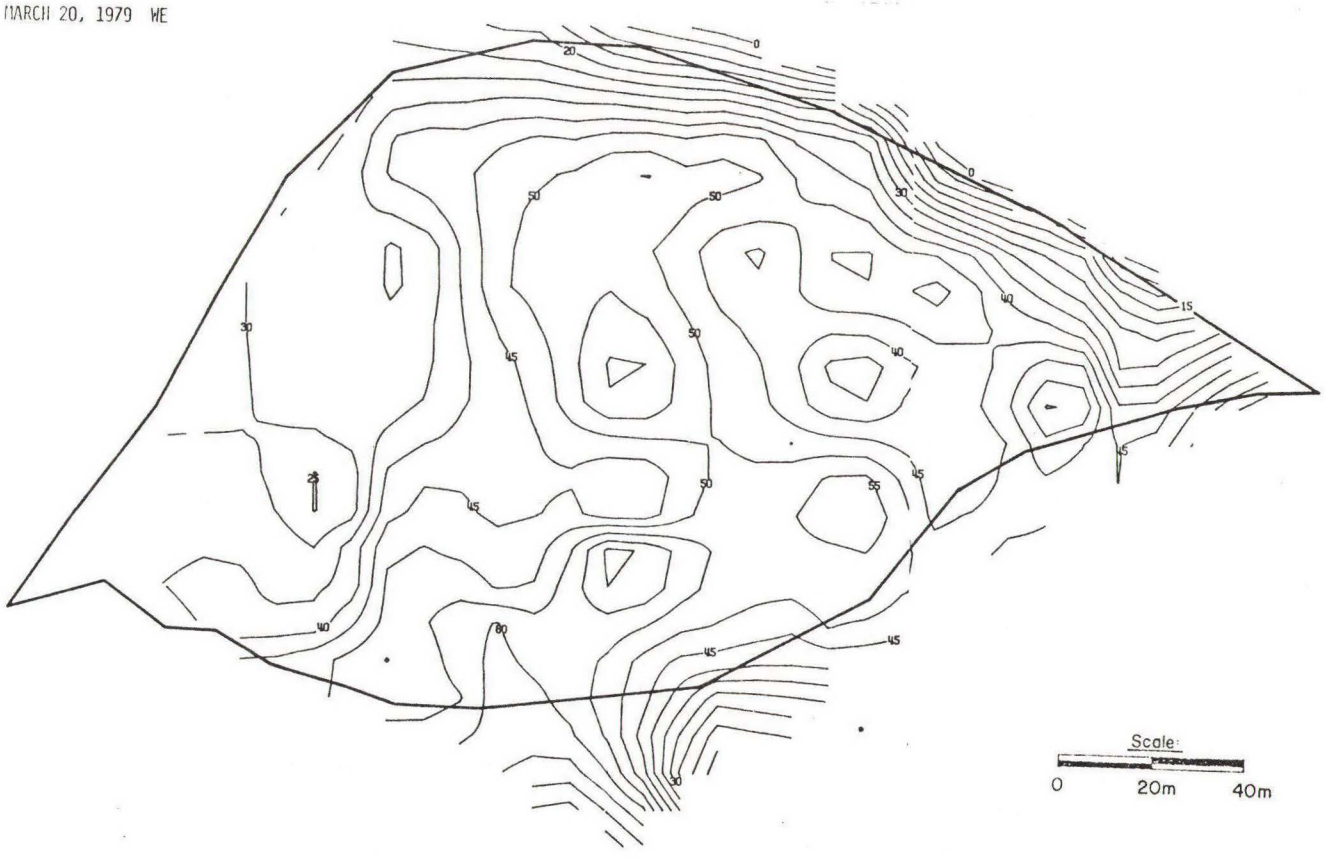


FIGURE 35: Maximum water equivalent of the 1979 season. March 20.

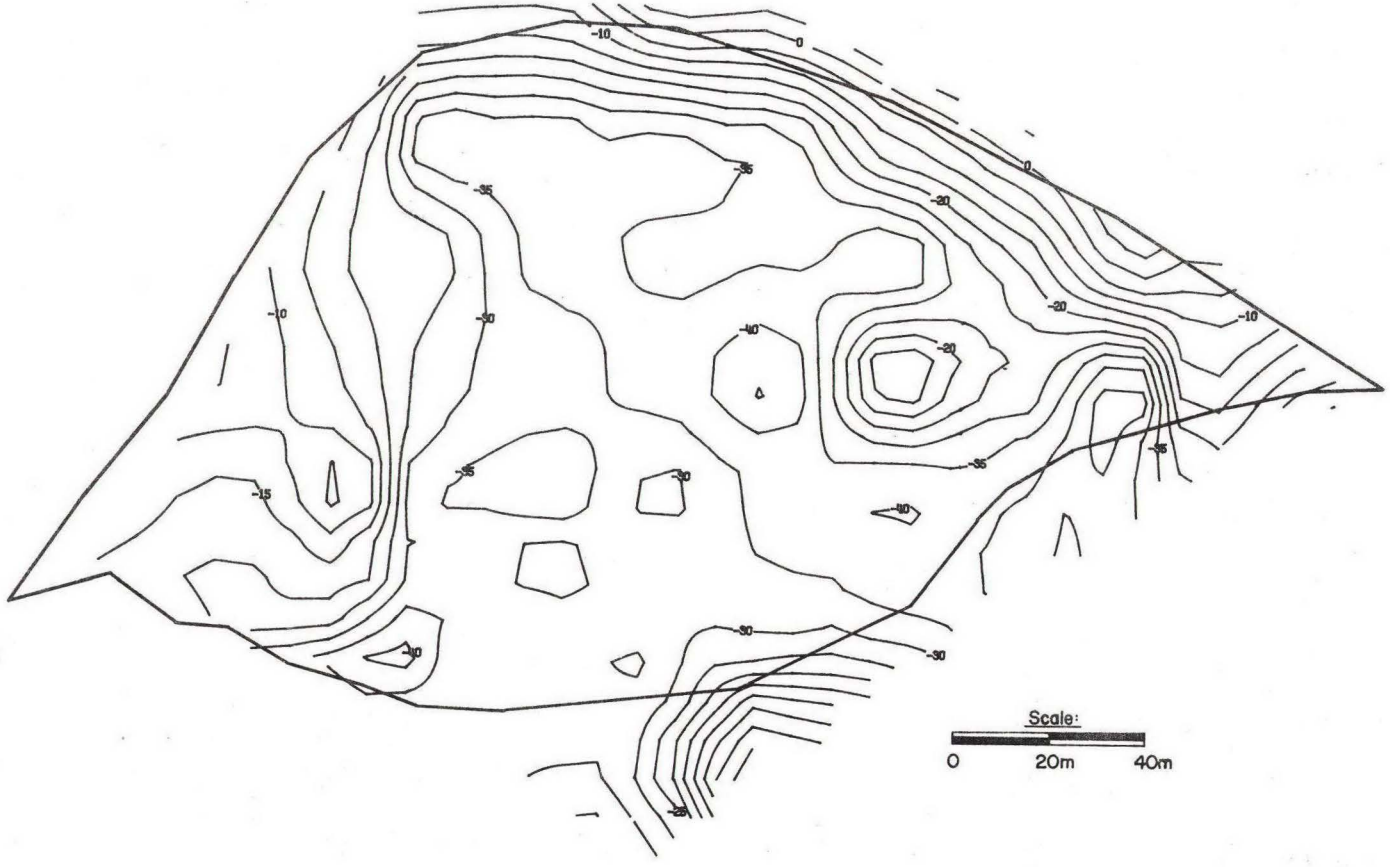


FIGURE 36: Maximum change in water equivalent during the 1978 season. May 4 to 23.

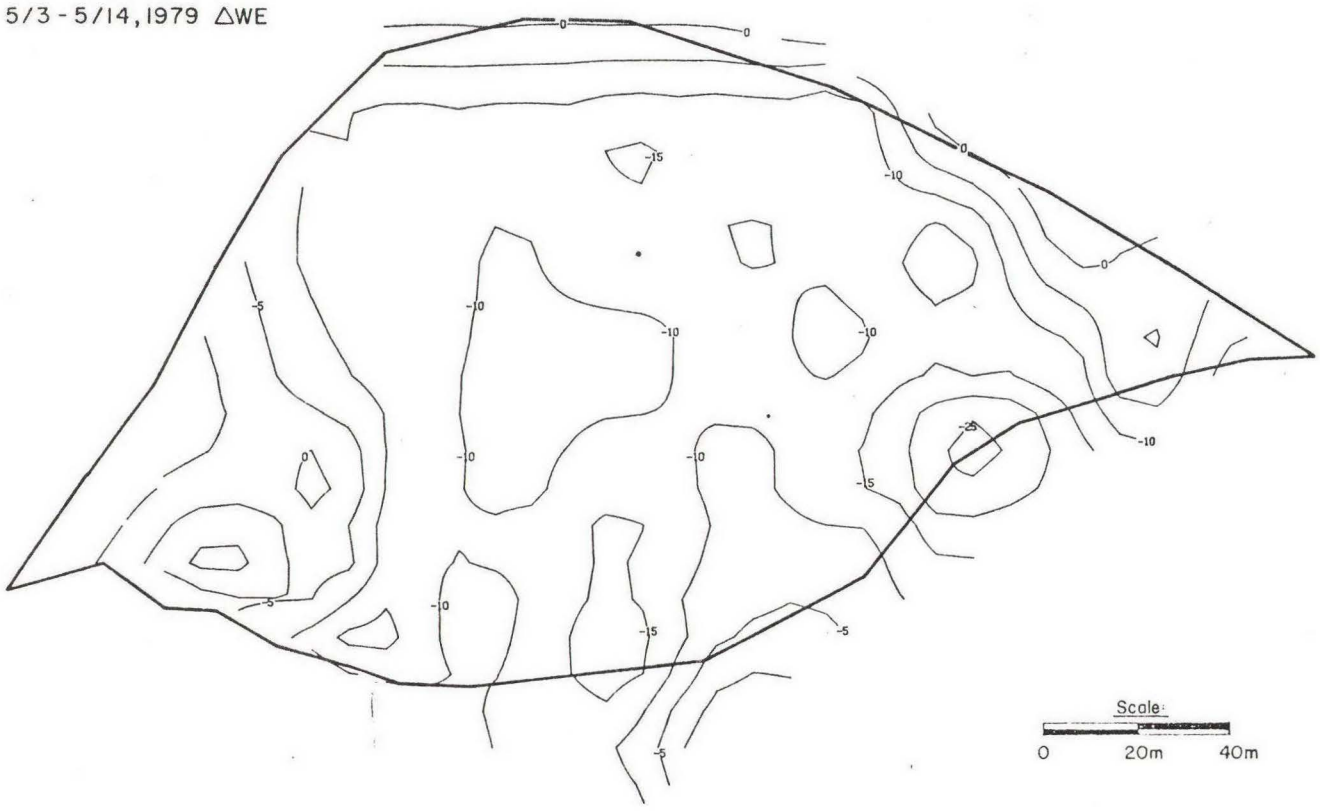


FIGURE 37: Maximum change in water equivalent during the 1979 season. May 3 to 14.

TABLE 6: Correlation coefficients for points with aspects greater than 200° (west side of dump) and those with aspects less than 200° (values in parentheses)

	Elevation Difference		Slope		Distance	
	Depth	Water Equivalent	Depth	Water Equivalent	Slope	Water Equivalent
December	.682	.573	--	--	.392	--
	(.497)	--	--	--	--	(-.581)
January	.628	.674	--	--	.319	.504
February	.602	.605	.440	.386	.437	.423
March	.591	.568	.403	.270	.438	.377
April	.656	.660	--	--	.502	.506

All correlation coefficients at 5% level or better are shown.

SNOW-EROSION RELATIONSHIPS

Snow Distribution

The spatial distribution of the snow and its melt pattern has a large influence on the erosion patterns. Also, it is not only the amount of snow but the manner in which it melts that determines the amount of erosion in any particular year. The snow data reported here were collected in March of 1978 and 1979 and represent the maximum accumulation measured for each year.

In 1978, the depth of snow was measured at 10 m intervals on each transect. To obtain the snow density, five or six measurements were made on one of the two transects on each dump and an average density computed. This average density was used to compute the snow water equivalent for all measurements on both transects on the dump. The average snow water equivalent for a transect was computed as the average of all the measurements made on that transect. The densities and snow water equivalents for all snow transects are shown in Table 7.

In 1979, the depth of snow and snow density were measured at 15 m intervals along each transect. This resulted in a measured snow water equivalent at each measuring point rather than a computed value as in 1978. As a means of checking 1978 values where the average density of one transect was used in the computations for both transects, the average density of each transect was computed by two methods (Table 7).

TABLE 7: Snow Summary

Location	Site	22 March 1978 Average* Density	22 March 1978 Average Snow W.E.	22 March 1979 Average Density	22 March 1979 Average Snow W.E.	22 March 1979 Average** Snow W.E.
		gm/cc	(cm)	gm/cc	(cm)	(cm)
Dump 6	Transect 1	--	12	0.34	10	11
	Transect 2	0.44	19	0.36	12	12
Dump 7	Transect 1s	0.45	28	0.36	19	19
	Transect 2s	--	29	0.36	20	20
Dump 8	Transect 1s	0.44	29	0.31	17	17
	Transect 2s	--	29	0.26	14	17
Dump 2	Overall	0.40	54	0.36	42	--
Slug Creek	Divide†	0.42	53	0.37	46	--

* From 5-6 density measurements on one transect on each dump.

** From 1973 average density on one transect, as was done in the 1978 analysis.

† Measurements made on 3/28/78 and 3/28/79. Soil Conservation Service Snow Course.

A comparison of the 1979 values of snow water equivalent computed by the two methods gives an indication of the validity of the assumption of equal snow densities in 1978. The average densities on the two Dump 7 transects were identical so it would make no difference which method of computation was used. For Dump 6, the densities for the two transects are essentially the same (6 percent difference). Thus for this dump, either of the methods of computing water equivalent would be valid. On Dump 8, however, the difference in density between the two transects is 19 percent. This may result in a computed 1978 water equivalent value for Transect 2 that is too high.

In both 1978 and 1979, the average snow water equivalents on Dump 7 were nearly the same for both transects, with Transect 2 having a slightly higher value in both years. Figures 38 and 39 show that the snow distribution pattern was very similar on both transects and in both years. At the top of the dump (slope length = 0 m) the snowpack is shallow, as a result of wind scour near the break in slope. On Transect 1, where there is a very gradual change in slope, the reduction in snow water equivalent is not as pronounced as on Transect 2 where there is a more abrupt break in slope. On both transects in both years, the snowpack increased from the top edge down the slope face reaching a maximum

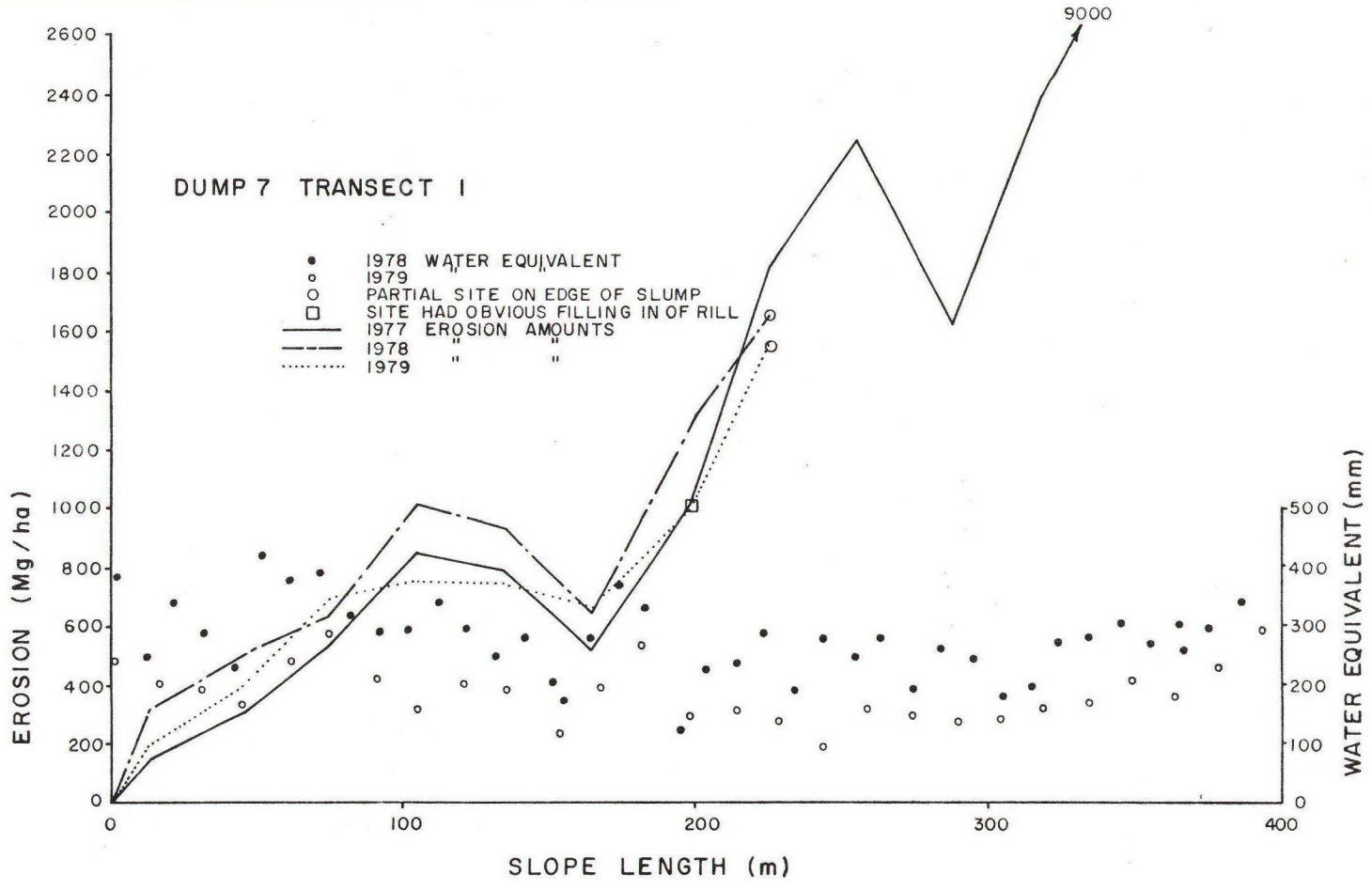


FIGURE 38: Water equivalent and erosion. Dump 7, Transect 1.

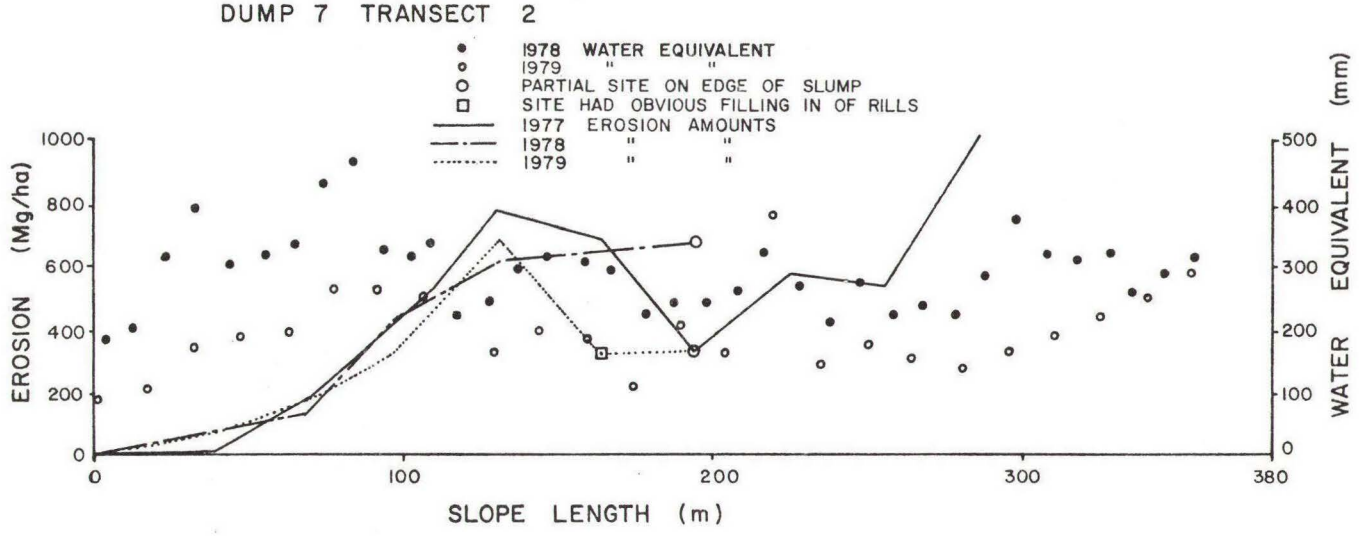


FIGURE 39: Water equivalent and erosion. Dump 7, Transect 2

at about 70-80 m, then declined slightly at about 120 m where it remained fairly uniform to near the bottom of the slope. From this point to the bottom of the slope there was an increase in the snowpack as the slope decreased. The high value of water equivalent at about 220 m on Transect 2 occurred in both 1978 and 1979, with no corresponding peak on Transect 1. A possible explanation is that snow deposition occurs at this point due to a drainage berm located at about a slope length of 200 m.

There is a reduced snowpack due to wind scour at the break in slope near the top of Dump 6 just as was found on Dump 7 (Figures 40 and 41.) On Dump 6, the scour zone is located at a slope length of 10-20 m due to a somewhat rounded ground profile. The high values from 0-10 m represent the windward edge of the snowdrift formation on the top of the dump (Chacho and Molnau, 1980). The accumulation patterns are consistent from year to year on each transect. Both transects had some bare ground near the bottom of the dump in both years. The occurrence of bare ground on Dump 6 and not on the other dumps is due to the southerly exposure of the dump face. From this bare ground down to the bottom of the slope, the snowpack increased as the slope flattened out to level ground.

As previously mentioned, Dump 8, Transect 2 water equivalent values may be 15-20 percent high for 1978. For both Transect 1 and Transect 2 (Figures 42 and 43) a reduction in snowpack near the top of the slope, similar to that of Dumps 6 and 7, is found. Transect 1 shows a departure from the consistent year to year distribution pattern found on all the other transects. Beginning at a slope length of about 220 m, the 1979 data are a mirror image of the 1978 data. The reason for this change in distribution is unknown.

A general comparison of the snow data from Dumps 6, 7 and 8 shows that in March 1978, the snow densities were higher than 1979, 0.45 gm/cc as compared to 0.26-0.36 gm/cc and that the amount of snow was also greater. This is consistent with the nearby Soil Conservation Service (SCS) Slug Creek Divide Snow Course where the density and snow water equivalent were 0.42 gm/cc and 53 cm and 0.37 gm/cc and 46 cm for 1978 and 1979 respectively (Table 7). The Dump 2 density and snow water equivalent of 0.40 gm/cc and 54 cm for 1978 and 0.36 gm/cc and 42 cm for 1979 compare very well with Slug Creek Divide. This agreement is due to the location of the sites. Snow courses are laid in somewhat sheltered areas much like the Dump 2 site which is fairly well protected from the wind.

Although the snow data from Dumps 6, 7 and 8 do not compare well quantitatively with either Slug Creek Divide or Dump 2, they do compare well qualitatively. All sites had higher densities in March 1978 than March 1979 reflecting

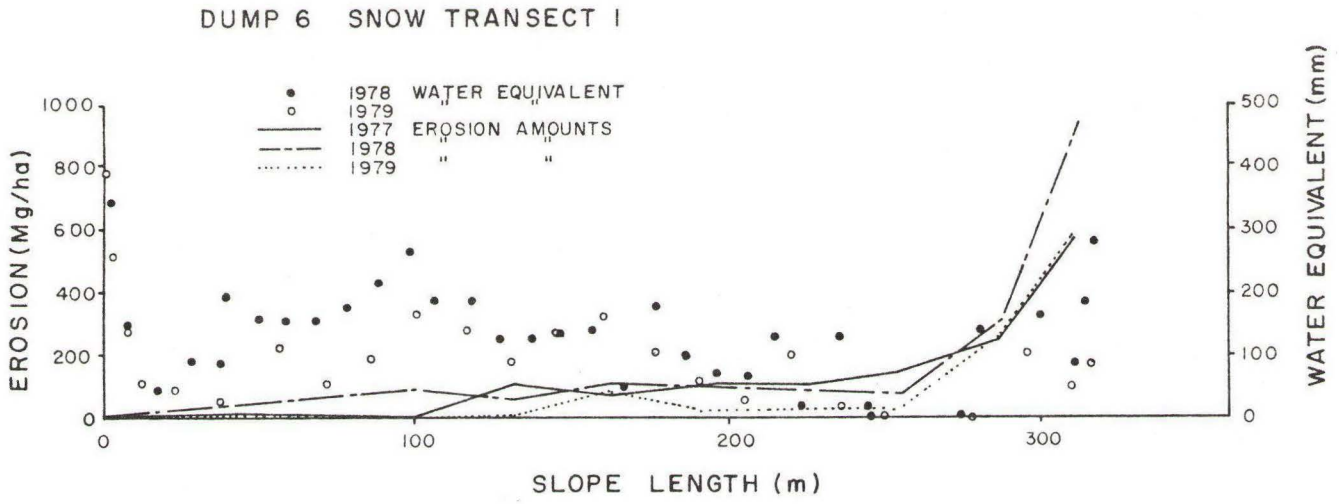


Figure 40: Water equivalent and erosion. Dump 6, Transect 1.

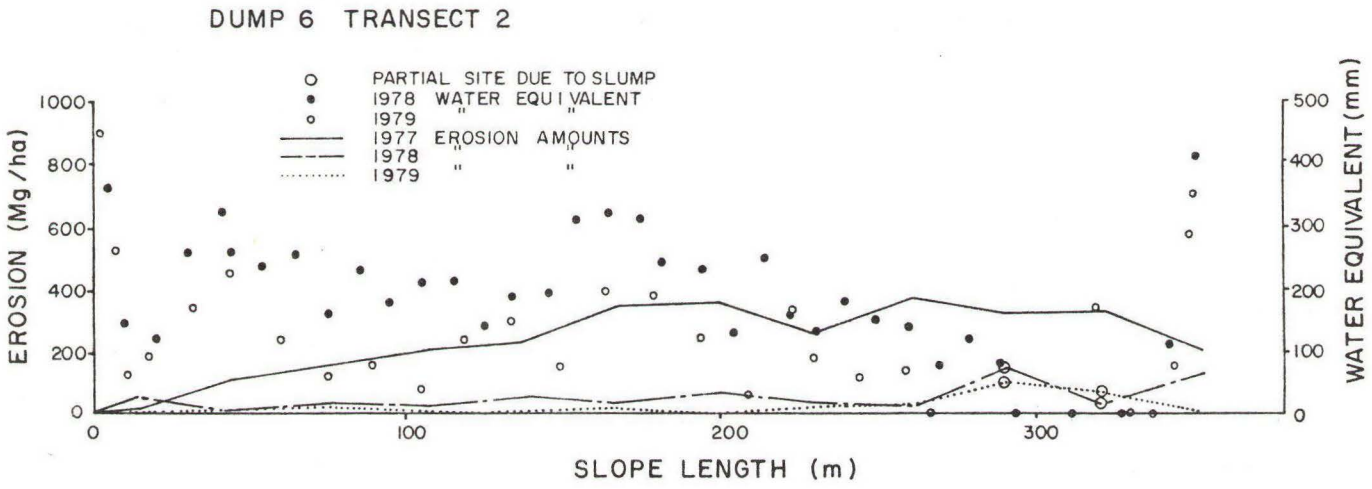


FIGURE 41: Water equivalent and erosion. Dump 6, Transect 2.

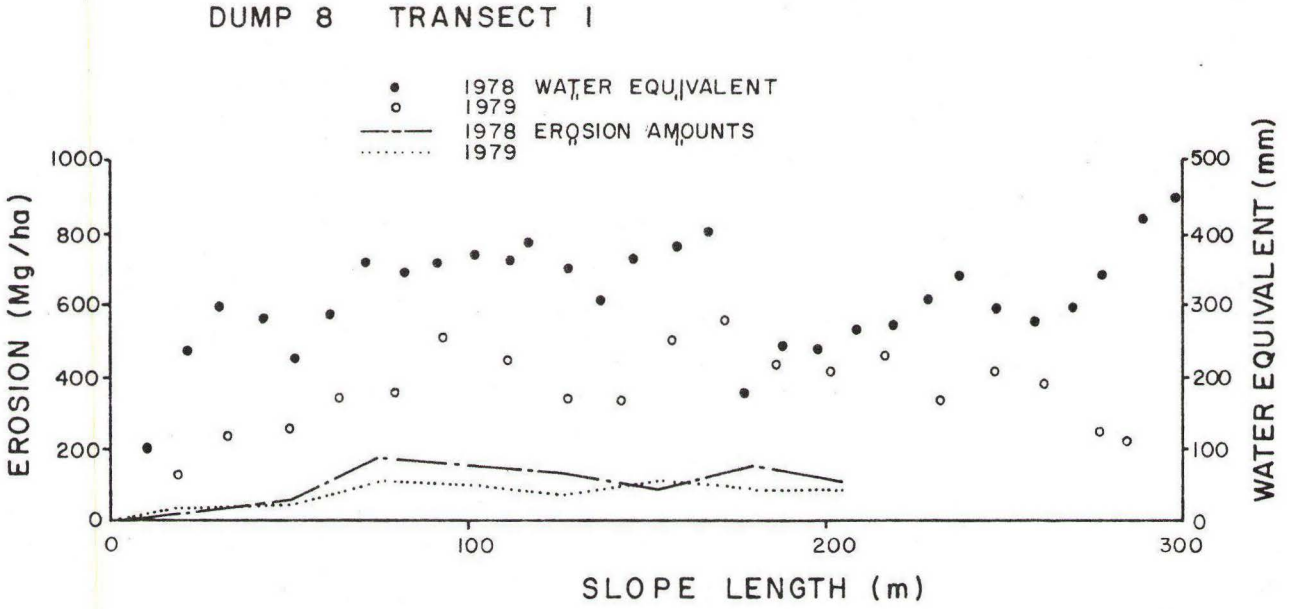


FIGURE 42: Water equivalent and erosion. Dump 8, Transect 1.

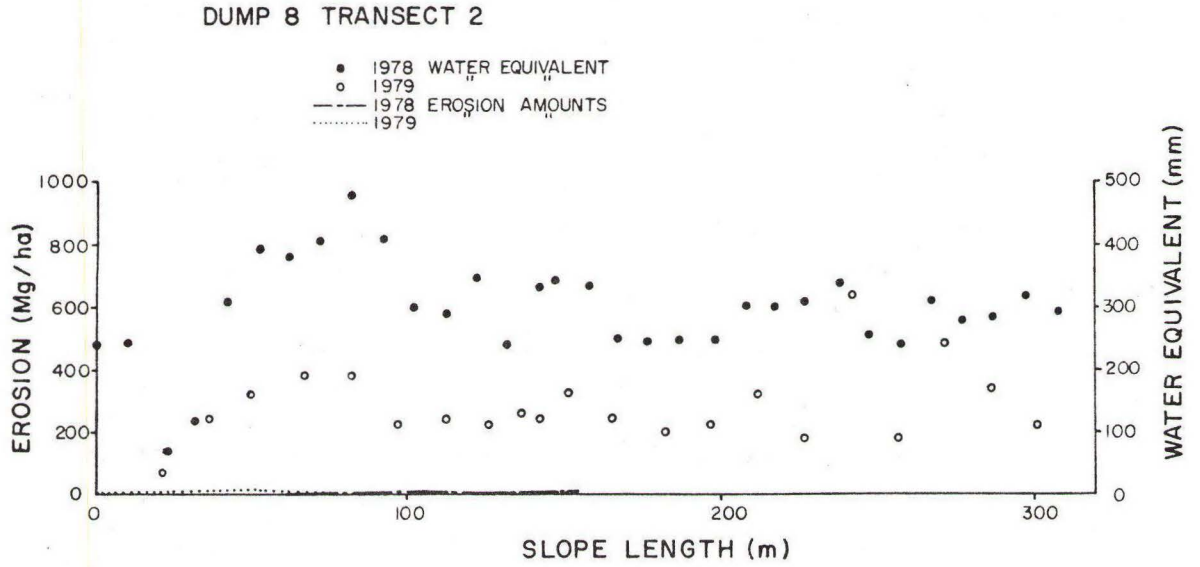


FIGURE 43: Water equivalent and erosion. Dump 8, Transect 2.

an earlier spring in 1978. Warmer temperatures in March 1978 resulted in some early snow melt which produced the higher densities. The lower snow water equivalents in 1979 on Dumps 6, 7 and 8 were also seen on Dump 2 and Slug Creek Divide. At Slug Creek Divide, the 1978 snowpack was about 17% higher than the fifteen year average of 45.7 cm while the 1979 snowpack was equal to the long term March average. In 1977, the density was 0.28 gm/cc and the snow water equivalent of 21.3 cm on March 31 was 45 percent of the long term average, showing the effect of the 1977 drought.

Snow-Erosion Relations

The erosion measured on Dumps 6, 7 and 8 varied tremendously from dump to dump. An inspection of Figures 38 to 42 reveals that there does not seem to be a direct correlation between amount of snow and amount of erosion measured for the years 1978 and 1979 when comparing the dumps individually. However, if the three dumps are treated as a group, a trend does appear. The erosion measured in 1978 and 1979 on Dumps 6 and 7 was essentially the same as that measured in 1977. This means that erosion resulting from the 1978 and 1979 snowpacks was negligible, at least for the measuring techniques used in this study.

At this point in the analysis, two entirely different conclusions can be reached. One is that most erosion occurs during the first year of dump life and then very little erosion occurs during the second and third years. To continue with this line of reasoning, little additional erosion would occur as the dump ages, so that essentially after one year the dump has stabilized for rill erosion. This occurred even though the 1977 snowpack was 47% of the long term average, as measured on the Slug Creek Divide Snow Course, and the 1978 and 1979 snowpacks were 117% and 100% of the long term average. It is generally expected that erosion is high on a new dump and decreases with age until a point of stabilization is reached after only one year. If the study had been conducted only on Dumps 6 and 7, this would be the logical conclusion. However, the inclusion of Dump 8 in the study in 1978 and 1979 leads to a second possible conclusion.

Dump 8 was finished in the fall of 1977 so that the 1978 erosion measurements represent the age one year erosion and should be comparable to the 1977 age one year measurements on Dumps 6 and 7. Figures 42 and 43 show that nearly no erosion occurred on Transect 2 in both 1978 and 1979 and only a moderate amount occurred on Transect 1 even though the first year measurements of 1978 followed a winter of about twice normal snowpack. The same pattern of little or no erosion in 1978 and 1979 on Dumps 6 and 7 was found on Dump 8, leading to the possible conclusion that dump age was not the major factor which produced the measured erosion pattern.

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APPENDIX A

INT Bozeman

4040 Cooperation May 11, 1977

Authorship of reports and use of data
from SEAM - University of Idaho Phosphate
Study (Supplement No. 51)

Gene Farmer, FSL, Logan
Bob Johnston, FSL, Logan
Myron Molnau, University of Idaho, Moscow
Dale Ralston, University of Idaho, Moscow

Some of us have discussed by phone the need to clarify the use of data and authorship of reports from the phosphate mine dump hydrology and erosion study. This clarification is necessary because of the number of individual researchers and organizations involved. Also, there will be a large amount of data of various types to be collected. This will offer the opportunity for many individual papers and summary reports with joint authorship. This memo is intended to be a draft agreement to be circulated for the comments of the individuals involved. If there is no objection, I will incorporate all comments and changes into a final agreement to be signed by all parties.

Phosphate Mine Dump Hydrology and Erosion Study

The following is a description of the data to be collected by research groups under the direction of the individual scientists as noted. This division of effort was agreed upon at a meeting at the Soda Springs District office on April 14, 1977.

Myron Molnau - Department of Agricultural Engineering, University of Idaho, Moscow.

1. Yearlong collection of basic weather data.
   a. Wind direction and wind run.
   b. Air temperature plus a limited amount of soil temperature data.
   c. Precipitation using a heated tipping bucket gage.
   d. Solar radiation at selected intervals with an Eppley pyranometer.

2. Snow survey using a Mount Rose tube to provide information on snow accumulation and ablation rates on the dump surface with time.

3. Estimates of snow melt rates on the dump surface by lysimeters, both recording and storage types.

4. Measurements of frost depth by means of a few frost tubes.

5. Estimates of gross erosion on the upper portions of the mine dump face by an erosion survey with a rillmeter.

Gene Farmer - U.S. Forest Service, Forestry Sciences Lab, Logan, Utah.

1. Measure soil water content by volume year around with nuclear equipment in about 60 access holes.

2. Measure soil water tension and soil temperature at depth in selected access holes.

3. Measure surface water runoff volume and sediment yield. The method will depend upon the study site selected for this work: dump 7 would have a sediment trap and water stage gage; dump 2 would require a sediment survey of an impoundment below the dump.

4. Estimates of biomass above and below ground, depending upon the availability of equipment.

5. Provide, if possible, a low-service, self-filling evaporation pan to supplement the basic meteorological information.

Dale Ralston - Idaho Bureau of Mines and Geology, University of Idaho, Moscow.

1. Measure the height of the phreatic surface under the dump. Observation wells will be located across the dump, but concentrated near the toe. Some wells will be equipped with recorders.

2. Evaluate the groundwater conditions in the underlying geologic materials by means of deep piezometer installations.

3. Measure selected chemical water quality parameters of the mine dump groundwater.

4. Attempt to describe the groundwater flow systems in the underlying geologic materials.

Division of Authorship

The cooperating scientists agree to a free exchange of data and to a division of authorship of reports according to the following four points:

1. Each cooperator will provide data for use by other cooperators on this joint study. This data will be examined and reduced before release to minimize errors in interpretation.

4. Measurements of frost depth by means of a few frost tubes.

5. Estimates of gross erosion on the upper portions of the mine dump face by an erosion survey with a rillmeter.

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1. Each cooperator will provide data for use by other cooperators on this joint study. This data will be examined and reduced before release to minimize errors in interpretation.

2. If a cooperator receives data and performs his own interpretation and/or analysis without assistance from the donating cooperator, then an acknowledgement of the data source in all reports will suffice.

3. If two or more cooperators are required to interpretate and/or analyze data for a report, then joint authorship of this report will be required.

4. The phosphate mine dump hydrology and erosion study is expected to generate large quantities of data of interest to scientists of several disciplines. The cooperators agree to publish several reports covering various aspects of the total data collection. These summary reports will provide the opportunity for each cooperator to be senior author on a report representing his specialty.

The foregoing is a draft agreement. Please send me your comments and changes so that I may develop a final draft for your formal approval.

Ed Burroughs

EDWARD R. BURROUGHS, JR.
Project Leader

ERBurroughs:drc

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